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THE FLORA OF THE ISLAND OF HANDA.

By

J. W. HESLOP HARRISON, D.Sc., F.R.S.

and

HELENA HESLOP HARRISON, M.Sc.

INTRODUCTION.

Handa* is a small uninhabited island, about a mile and a half long and a mile broad, lying off the Sutherland coast to the north-west of Scourie. Geologically speaking, it is built of red sandstone, and appears from Tarbet, from which it is best approached, to rise abruptly to the fifty foot level and then gently, across a more or less undulating moorland interspersed by a series of lochans, to Sithean Mor (406 feet) in the extreme north. From this hill, the highest point on the island, a sharp fall succeeds to the 250 feet contour line, marking the maximum height of the really magnificent and almost perpendicular cliffs which afford shelter to countless seabirds.

As one approaches Handa, to the west of the harbour, and stretching three-quarters of a mile along the coast and quite an appreciable distance inland, well developed sand dunes come into view. Beyond these dunes the island conveys the impression of a dull unrelieved barrenness which is only increased on further exploration.

Every conceivable agency released by human interference in the way of overgrazing by sheep, nibbling by thousands of rabbits, incessant firing, and excessive and injudicious draining seems to have played its part to produce a picture of desolation, fortunately rarely encountered. As a result of these observations, grave misgivings were forced into one's mind as to the wisdom of the prevalent practice of firing heather on peat moors and, when carried out, of deep, random draining. In my opinion, the loss of soil and the increase in the heather beetle on many a Highland moor and Scottish island have resulted from such ill-directed activities.

*The island forms part of V.-C. 108.

Be that as it may, one redeeming feature, as far as vegetation was concerned, was noted, and that was the massing of plants in a haven of refuge on the lower eastern and southern cliffs. Contrasting this with the paucity of the flora of the exposed areas, and realising how the scarcity had been brought about, one could readily imagine the rôle played by such cliffs in protecting plants from the wholesale destruction so often pictured as taking place during the Glacial Period or Periods. Thus was strengthened the views forced on us after our studies on the cliffs of eastern Raasay.

The cliffs on the north, north-west and elsewhere, although they bore species not observed elsewhere, are not so rich in plants simply because they are monopolised by the seabirds for which the Handa is deservedly famous.

THE LIST OF PLANTS.

Thalictrum dunense Dum.
This plant, rare enough in Ross and Sutherland, was plentiful and in fine condition on the cliffs; not noted on the dunes.

Ranunculus Flammula L.
Scattered in damp places on the moorlands.

R. acris L.
Not common; chiefly on the dunes.

R. repens L.
Scattered and occurring on the cliffs also.

Caltha palustris L.
Very rare and only found in a stream which ended blindly on the dunes.

Cochlearia officinalis L.
On rocks.

C. groenlandica L.
On rock ledges; not uncommon.

Viola palustris L.
Well distributed.

V. Riviniana Reich.
Casually on cliffs and dunes, also in grassy places.

V. canina L.
Sparingly on the dunes; new to V.C. 108.

Polygala dubia Bellynck.
Moors, local.

P. serpyllacea Weihe.
Rare, but widespread.

Silene maritima With.
On the higher northern cliffs.

Lychnis dioica Mill.
With the preceding.

L. Flos-cuculi L.
Quite rare in damp places.

Cerastium viscosum L.
Abundant on dunes etc.

C. vulgatum L.
Plentiful in similar stations.

Stellaria media L.
Chiefly near deserted crofts.

Sagina procumbens L.
Dunes etc.

Montia fontana L.
As var. *lamprocarpa* in drainage cuttings, etc.

Hypericum pulchrum L.
On the cliffs; not common.

Linum catharticum L.
On a grassy slope on one of the cliffs.

Geranium molle L.
Plentiful on the sand dunes.

Lotus corniculatus L.
Common on the cliffs, rare elsewhere.

L. uliginosus L.
Very rare; one or two plants growing amongst *Iris* in the south west; new to V.C. 108.

Trifolium pratense L.
Common; cliffs and dunes.

T. repens L.
As with the preceding.

Vicia Cracca L.
On cliff ledges; not common.

V. sepium L.
In similar places.

Spiraea Ulmaria L.
In wet places near the sea and on the cliffs; not really common.

Potentilla erecta Hampe.
Common enough on the moors.

P. Anserina L.
Common as a shingle plant.

Rosa spinosissima L.
Quite rare on cliff ledges.

Sedum roseum Scop.
Well distributed on the cliffs.

S. acre L.
Only on the dunes and there common.

Drosera rotundifolia L.
Principally in the centre of the island and not rare.

D. anglica Huds.
Occasionally with the preceding.

D. longifolia L.
Rare along the edge of a stream issuing from one of the lochans.

Callitriche stagnalis Scop.
In cuttings near old crofts.

C. intermedia Hoffm.
Rare with the former.

Epilobium montanum L.
Not rare.

E. obscurum Schreb.
Nearly as common.

E. palustre L.
Common enough.

Ligusticum scoticum L.
On more exposed cliffs.

Angelica sylvestris L.
Only on the cliffs.

Heracleum Sphondylium L.
On the southern cliffs.

Daucus Carota L.
Grassy slopes on cliffs in the south.

Galium verum L.
On the sand dunes and lower cliffs.

G. saxatile L.
On the moors.

G. palustre L.
Often in cuttings.

G. Aparine L.
On shingle and rarely amongst *Iris*.

Scabiosa Succisa L.
None too common on moors.

Solidago Virgaurea L.
Southern cliffs on ledges.

Bellis perennis L.
Chiefly on the dunes.

Achillea Millefolium L.
In the south of the island.

A. Ptarmica L.
Rare in wet places.

Matricaria inodora L.
On shingle, but the var. *maritima* on the higher cliffs.

Senecio Jacobaea L.
Scattered on cliffs and dunes.

S. aquatica Hill.
Rather rare in wet places.

Cnicus lanceolatus Willd.
Common generally.

C. palustris Willd.
Less well scattered.

C. arvensis Hoffm.
Chiefly on dunes and near old crofts.

Centaurea nigra L.
On the cliffs; rare.

Crepis capillaris Wallr.
Common, dunes etc.

Hieracium crocatum Fr.
Very rare on the cliffs, but, nevertheless, carrying the gall-wasp, *Aulacidea hieracii*.

Hypochoeris radicata L.
Dunes, quite rare.

Leontodon autumnale L.
With the preceding.

Taraxacum laevigatum DC.
On the sand dunes.

T. spectabile Dahl.
In damp places on the cliffs.

Sonchus oleraceus L.

S. asper Hill.

S. arvensis L.
All three species chiefly near the sea in south.

Vaccinium Myrtillus L.
Extremely rare on moors.

Calluna vulgaris Hull.
Plentiful enough.

Erica tetralix L.
Not common.

E. cinerea L.
Distinctly rare.

Armeria maritima Willd.
Well distributed on cliffs.

Primula vulgaris L.
Not rare, cliffs in the south.

Lysimachia nemorum L.
Damp spots on cliffs.

Anagallis tenella L.
In one drainage cutting and on the cliffs in the south.

Gentiana campestris L.
Rare on cliffs only.

Menyanthes trifoliata L.
Not plentiful in the lochans.

Myosotis caespitosa Schultz.
Rare in one or two cuttings.

M. arvensis Hill.
On the dunes.

M. versicolor Sm.
Common on the dunes.

Euphrasia borealis Towns.
Under cliffs in the centre of the island.

E. brevipila Burn & Grem.
Fairly common.

E. foulaensis Towns.
Rather rare on a central escarpment.

E. gracilis Fr.
On cliffs.

E. scotica Wettst.
Scattered on less bare patches on the moors.

Pedicularis palustris L.

P. sylvatica L.
Both species are well distributed, but never plentiful.

Pinguicula vulgaris L.
On cliffs and moors; often common.

P. lusitanica L.
Occasional and locally common.

Thymus Serpyllum L.
Sparingly, cliffs etc.

Prunella vulgaris L.
Locally common.

Ajuga reptans L.
Damp places on cliffs, not plentiful.

Plantago Coronopus L.
Abundant on cliffs.

P. maritima L.
Also common in suitable localities.

P. lanceolata L.
Less widely spread.

P. major L.
On the dunes.

Littorella uniflora Asch.
Common in the lochans.

Atriplex patula L.
On shingle.

A. glabriuscula Edm.
Also on shingle, even in the north.

Rumex obtusifolius L.

R. crispus L.
Both chiefly on shingle and the dunes.

R. Acetosa L.
On the cliffs.

R. Acetosella L.
Moors but never abundant.

Urtica dioica. L.
Near old habitations and on shingle.

Salix aurita L.
On the moors, but always very dwarf owing to firing.

S. cinerea L.
Scarce; on the cliffs only.

S. repens L.
Plentiful and well distributed, but the plants are rarely well-grown.

Populus tremula L.
Rare on the cliffs.

Empetrum nigrum L.
Never abundant; on moors.

Orchis purpurella Stph.
In damp less burnt patches on the moors; a new county record.

O. elodes Gris.
Quite rare on the moors.

Iris pseudacorus L.
Locally plentiful in the south near the sea.

Narthecium ossifragum Huds.
Somewhat rare.

Juncus bufonius L.
In drainage cuttings.

J. squarrosus L.
On the moors.

J. conglomeratus L.

J. bulbosus L.

J. sylvaticus Reich.

J. articulatus L.
All four species widely scattered, but distribution obviously broken by drainage and firing.

Sparganium angustifolium Michx.
Common on one loch.

Potamogeton natans L.
In one lochan.

P. polygonifolius Pourr.
Common in dampish places and drainage cuttings.

Eleocharis multicaulis Sm.
On moorlands.

Scirpus pauciflorus Lightf.
Also on the moors.

S. caespitosus L.
With its congener and even more plentiful.

Schoenus nigricans L.
Not common and restricted to the cliffs facing the mainland.

Carex arenaria L.
On the dunes and extending to the cliffs.

C. echinata Murr.
Not common.

C. leporina L.
Quite local and rare.

C. Goodenowii Gay.
Common in less burnt areas.

C. pilulifera L.
Occasional on moors.

C. caryophyllea Lat.
Not very common.

C. binervis Sm.
Well distributed but not plentiful.

C. flava L.
Fairly common but local.

Anthoxanthum odoratum L.
On the moors and cliffs.

Agrostis canina L.
The most abundant grass.

A. alba L.
Fairly widespread.

A. tenuis Sibth.
Common enough.

Calamagrosis epigeios Roth.
One colony on the cliffs east of the harbour. This constitutes a "furthest north" station in Britain, and provides a new county record.

Ammophila arenaria Link.
Abundant on the dunes and even ascending to the cliffs.

A. baltica Link.
This interesting new find grew on the cliffs with *Calamagrostis epigeios* at the point where that plant and *A. arenaria* clashed This affords strong evidence that *A. baltica* results from a crossing of the two grasses just named. It should, however, be noted that the inflorescences were much more compact than in the case of the Ross Links plant. New to Scotland and, of course, a new county record.

Aira praecox L.
On the dunes and other dry grassy places.

Deschampsia flexuosa Tr.
Well distributed, but not so common as one would expect.

Holcus mollis L.

H. lanatus L.
Both of these were quite rare, although of freer occurrence on the cliffs.

Arrhenatherum tuberosum Gilib.
Far from common.

Avena pubescens Huds.
Restricted to one grassy bank on the southern cliffs.

Sieglingia decumbens Bernh.
To be found sparingly everywhere.

Cynosurus cristatus L.
Very rare; cliffs only.

Molinia caerulea Moench.
Thinly scattered everywhere.

Catabrosa aquatica Beauv.
Local in damp places between dunes and sea.

Poa annua L.
Quite common.

P. pratensis L.
Also not uncommon.

G. declinata Breb.
In one drainage ditch; new to V.-C. 108.

Festuca capillata Lam.
Not common.

F. ovina L.
Only one patch of the var. *vivipara* near the larger loch.

F. rubra L.
Common with var. *glaucescens* on rocks near the sea.

Agropyron junceum Beauv.
On the cliffs near the *Calamagrostis.*

Lolium perenne L.
Near old crofts.

Nardus stricta L.
Not really plentiful.

Juniperus sibirica Burgsdorf.
A few enormous weather-beaten clumps on the cliffs facing the mainland, and near the harbour.

Pteris aquilina L.
Common enough.

Blechnum Spicant With.
Rare under rocks and on the sides of cuttings.

Asplenium Adiantum-nigrum L.
Rare on rocks and cliffs.

Lastrea Filix-mas Presl.
Very rare.

Phegopteris polypodioides Fée.
Also rare in stony places.

Equisetum arvense L.
Sparingly near old cultivation.

E. palustre L.
Damp places near the dunes.

E. limosum L.
In the lochans but only sparingly.

Selaginella selaginoides Gray.
Rare on slopes on the cliffs.

A CONTRIBUTION TO OUR KNOWLEDGE OF THE LEPIDOPTERA OF THE ISLANDS OF COLL, CANNA, SANDAY, RHUM, EIGG, SOAY AND PABBAY (INNER HEBRIDES), AND OF BARRA, MINGULAY, AND BERNERAY (OUTER HEBRIDES).

By

J. W. Heslop Harrison, D.Sc., F.R.S.

Introduction.

In continuation of our investigations into the Flora and Fauna of the Hebrides, a third expedition was organised in 1937 by the Department of Botany, King's College, University of Durham. Although Pabbay remained untouched, as we had otherwise more or less completed our labours in the islands lying between Skye and Ross-shire, it was decided to confine our major efforts to the islands situated to the south of Skye. For many reasons, our headquarters were fixed on Soay, a small island, just off Skye, overshadowed by the Cuillin Mountains. From that island long excursions were made by motor-boat to Canna, Sanday, Rhum, and Eigg with extremely satisfactory results, more especially from the botanical standpoint, although their Entomology was not by any means neglected. Naturally, as we were compelled to return to Soay in the evening, the list of Lepidoptera recorded here from that island is much more complete than those from Rhum, Eigg, Canna, and Sanday.

Toward the end of the expedition, in view of our intention to give the problems presented by the eastern cliffs of Raasay further study, we once more took up our abode there. Fortunately, owing to the kindness of Mr. Sam MacLean, whilst located on Raasay we were enabled to give the Flora of Pabbay, situated about seven miles to the south-east, a very thorough survey. At the same time, although it is realised that the results of our labours can be materially extended, the Lepidoptera yielded an adequate return for the attention they received.

In addition to the efforts of the main party, prior to its arrival, Dr. W. A. Clark and Dr. G. Heslop Harrison paid visits to Coll, Barra, Mingulay, and Berneray, when the latter worker devoted some time to the Lepidoptera. The outcome of his researches, as far as that group is concerned, is incorporated here.

It should, however, be carefully noted that for very obvious reasons, great care was taken to do no organised work on Barra, only casual observations, made whilst awaiting the departure of the boat for Mingulay and Berneray, being set forth here.

NYMPHALIDAE.

Argynnis aglaia L.

Although the fact has not been generally realised until recently, this butterfly is one of the commonest and most widely distributed butterflies in the Western Islands—both Inner and Outer. We captured it on Soay, Rhum, Canna, Sanday, Barra, Mingulay, and Berneray. On Soay, it frequented the moorlands to the north of the islands and was especially at home in hollows near the lochans. Probably owing to heather-burning, it was rare to the south. On Rhum and Canna, we found it in similar places and on the sand-dunes.

As is generally the case in the Hebrides, the females are referable to the race *scotica* of Watkins, although they rarely show the extreme tendencies toward melanism exhibited in specimens captured on South Rona or in the Lewisian Gneiss areas in Raasay. Soay and Canna specimens, the former more especially, were the darkest forms taken.

A. selene L.

We were just too late for this species, but it had clearly been common on Soay and around the shores of Loch Coruisk, Skye, for examples worn to shreds were still to be captured in both areas during the first week of August. These examples were small and dark, and, of course, appertained to the race *insularum* Harrison described from Raasay and Scalpay.

Aglais urticae L.

This species was found on every island, in many cases looking much more strongly marked than it does in the north of England; larvae could still be found in August.

Although it cannot breed in such localities owing to the absence of nettles, *A. urticae* has a curious habit of flying to the highest points on the islands and staying there.

Nymphalis io L.

Last year we reported this insect from Raasay whilst other investigators recorded it from Barra, Cara, Scarba and Argyllshire; this season Dr. G. Heslop Harrison detected a hibernated specimen on Coll, and later a further example on Barra. Clearly the impetus driving it to extend its northerly range is not yet spent.

Vanessa atalanta L.
On Coll, Eigg, Canna, and Sanday.

V. cardui L.
During our unsuccessful quest for larvae of *Nyssia zonaria* on the sand dunes in the north-east of Rhum, we found larvae of this species abundant on thistles. In many cases the larvae, instead of constructing their tents from the leaves, had spun the radical leaves to the sand and were sheltering underneath them. Imagines also on Coll.

SATYRIDAE.

Eumenis semele L.
Very abundant on Canna, Sanday, Rhum, and less so on Soay, Mingulay, and Berneray. On Rhum, the species seemed to be restricted to the dunes, whilst on Sanday and Canna its range extended from the dunes to the tops of the highest cliffs. On Soay it was very local on the rocks between the two harbours.

Maniola jurtina L.
Really magnificent forms of the var. *splendida* swarmed on every island, those on Coll, Canna, Mingulay, and Berneray being especially noteworthy. On the other hand, most of the Pabbay forms were quite dull in appearance. This difference, when the facies of Raasay specimens is taken into consideration, may be of zoogeographical importance.

Erebia aethiops Esp.
In spite of very careful examination of a series of suitable *Molinia* colonies on Soay and elsewhere, except for a single example on Rhum, no other individuals of this species were seen. This seems remarkable in view of the abundance of the species on Raasay and Scalpay and at the nearest point on the mainland, Arisaig.

Coenonympha tullia Mull.
As var. *scotica* this species abounds amongst *Molinia caerulea* on Soay, Rhum, and Coll. It was noticed in much less quantity on Canna and Mingulay, whilst a single representative alone occurred on Pabbay.

C. pamphilus L.
This was captured, but not in great numbers, on every island except Barra. It seems certain that it will be taken there.

LYCAENIDAE.

Callophrys rubi L.
In spite of prolonged sweeping operations, during which *Calluna, Erica, Empetrum* and *Vaccinium* were swept, no larvae of this species were noted in Soay, Rhum, Canna or Eigg. It was, however, netted by Dr. G. Heslop Harrison on Coll in April.

Polyommatus icarus Rott.
The common Blue was abundant enough, clearly as a long-drawn out single brood, on all the islands. In the females var. *caerulea* prevailed, but it should be emphasised that Berneray and Mingulay specimens were much smaller than usual.

Pieris napi L.

This species was plentiful everywhere, from the sea coast and up the ravines, on every island in the Inner Hebrides where *Cardamine* species grew. On Coll, the first brood appeared in the middle of April, whilst on Soay the second brood commenced to emerge late in July. A single specimen from Barra affords, I believe, a new record from that island. All the specimens bore a close resemblance to Raasay and Skye forms; although dark, they were very distinctly lighter than Fifeshire insects.

P. rapae L.

One specimen was noted on Canna, and another on Barra; the species was much more plentiful on Eigg.

P. brassicae L.

On Pabbay this species simply swarmed as larvae and pupae, the former in the middle of the island where cabbages were growing, and latter on the walls of the single house on the island near the shore. The pupae were remarkably uniform in colour for they approximated very closely to the "rough-casting" of the house walls. No parasitism was detected in either case, but there was a heavy mortality amongst the pupae; which would indicate that the species is not really suited to the climate of these islands.

On Canna it occurred but rarely whilst odd examples were noted on Barra. The Berneray light-house keeper indicated that, on occasion, the species is to be found there.

SPHINGIDAE.

Smerinthus populi L.

Sparingly on Soay and Pabbay but more plentiful on Rhum and Eigg feeding on *Salix aurita* and *Populus tremula;* on *S. repens* on Canna.

NOTODONTIDAE.

Cerura furcula L.

Larvae beaten sparingly from *Salix repens* on Soay.

Dicranura vinula L.

Not uncommon on Eigg, Pabbay, and in the north of Soay, but only found in a gorge on the lower slopes of Barkeval, Rhum.

Pheosia tremula Cl.

On Eigg only.

P. dictaeoides Esp.

Common on birch on Soay, chiefly around Camas nan Gall.

Notodonta ziczac L.

On Salices on the banks of a stream flowing from Mullach Mor, Rhum, and rarely on Soay.

N. dromedarius L.

Common as larvae on birch on Soay but on alder on Canna, Rhum and Pabbay; imagines also on Soay.

Lophopteryx camelina L.

Widely distributed on Rhum, Eigg, Canna, Soay, and Pabbay.

Phalera bucephala L.

As eggs or small larvae on various trees and shrubs on Canna, Rhum, Eigg, Soay and Pabbay; quite common.

Pygaera pigra Hufn.
Thinly scattered on Rhum, Canna, and Soay; as usual on these islands on *Salix aurita* and not *S. repens*.

THYATIRIDAE.

Palimpsestis or F.
Larvae common on aspen on every island of the Inner Hebrides; generally on cliffs.

P. duplaris L.
On birch, Soay and Rhum.

Polyploca flavicornis L.
Larvae on birch around the two harbours on Soay, and in the north.

LYMANTRIIDAE.

Orgyia antiqua L.
Larvae on birch on the south side of Soay Harbour.

LASIOCAMPIDAE.

Lasiocampa quercus L.
Larvae of var. *callunae* Palmer on Canna, Eigg, Rhum, Soay, and Coll; generally on *Calluna* but occasionally on Salices.

Macrothylacia rubi L.
Only noted on Eigg.

Cosmotriche potatoria L.
Taken freely as eggs, larvae, pupae, or imagines on Canna, Rhum, Soay and Pabbay; practically restricted to *Molinia caerulea* as foodplant. As in the case of our Raasay and Scalpay captures, these occurrences indicate a considerable extension of the known range of the species.

SATURNIIDAE.

Saturnia pavonia L.
Generally on Canna, Rhum, Eigg, Soay, and Coll.

DREPANIDAE.

Drepana falcataria L.
Very rare; Soay only.

D. lacertinaria L.
Common on Soay, and less so on Rhum.

CHLOEPHORIDAE.

Hylophila prasinana L.
Larvae from oak on Eigg.

ARCTIIDAE.

Spilosoma menthastri Esp.
Larvae on Pabbay and Eigg.

S. lubricipeda L.
Larvae on the same pair of islands.

Phragmatobia fuliginosa L,
Soay only.

Arctia caja L.
Eggs and young larvae on Soay, larvae on Eigg, Canna, Rhum, and Pabbay.

Hipocrita jacobaea L.
Small larvae on Ragwort on Soay; only one lot seen between Loch Mor and Camas nan Gall.

NOCTUIDAE.

Demas coryli L.
Not uncommon on birch on Soay.

Acronycta leporina L.
Larvae very variable and far from rare on Soay; a species *not* noted in Raasay, Rona, or Scalpay.

A. rumicis L.
Exceptionally abundant, especially on Canna and Pabbay and also found on Eigg, Rhum, Sanday and Mingulay. Although the species is a general feeder, it seems to prefer *Iris pseudacorus.*

A. menyanthidis L.
Larvae common on *Calluna, Salix, Betula, Myrica,* etc. Eigg, Rhum, Canna, Soay, Pabbay.

A. psi L.
Rare on Eigg and Soay.

Agrostis cursoria Hufn.
As var. *armena* on the dunes of Kilmory, Rhum.

A. nigricans L.
Taken on Eigg only.

A. tritici L.
More or less typical forms captured at Ragwort on Rhum and Soay.

A. ripae Hb.
A single specimen captured by my colleague Dr. K. B. Blackburn near Kilmory, Rhum.

A. lucernea L.
Variable within a somewhat narrow range around var. *renigera* and common on Mingulay and Berneray.

A. strigula Thbg.
Rare on Soay.

A. augur Fab.
On Ragwort, Soay.

Noctua glareosa Esp.
Typical forms and var. *rosea* Tutt, Eigg; larvae on Coll.

N. baja Fab.
At flowers on Soay.

N. c-nigrum L.
Only detected on Eigg.

N. brunnea Fab.
On Eigg and Coll.

N. primulae Esp.
With var. *subrufa* Haw. on Soay.

N. xanthographa Fab.
Plentiful, with many of the examples of var. *rufa* Tutt facies. Canna, Eigg, Sanday, Soay, Coll, Berneray, and Mingulay.

Triphaena comes Hb.
Larvae abundant on Coll from which a heavy percentage of var. *rufa* Tutt, and *rufo-nigrescens* Tutt was bred. also on Eigg and Canna, where the type and nearly typical forms prevailed. A single worn example from Mingulay in all probability be referred to var. *rufo-grisea* Tutt; also on Barra.

T. orbona Hufn.
Very rare on Eigg.

T. pronuba L.
Not at all rare, var. *brunnea,* Tutt, var. *ochrea* Tutt and the type predominating; on Coll, Tiree, Soay, Eigg, Canna, and Berneray.

T. ianthina Esp.
As var. *rufa* Tutt on Loch Scresort, Rhum, Canna and Soay, var. *purpurascens* Harrison, Soay, var. *virgata* Harrison, Soay and Coll, var. *peacocki* Harrison Soay. A single specimen var. *rufa* on one side and var. *peacocki* on the other was captured from Ragwort on Soay.

Mamestra oleracea L.
Larvae on Eigg, Canna, Mingulay and Pabbay; common.

M. contigua Vill.
Not common on Soay and Rhum.

M. glauca Hb.
Larvae not rare on heather on Rhum and Soay; this species occurs on Raasay, but was accidentally omitted from the Raasay list.

M. pisi L.
Not seen on Pabbay, but of free occurrence on Coll, Rhum, Eigg, Canna, Sanday, and Soay.

Dianthoecia nana Rott.
On Canna, Rhum, Soay, and Pabbay, chiefly on *Lychnis Flos-cuculi.*

D. capsincola Hb.
Far from rare as larvae on pods of *Lychnis diurna* on Canna, rare on Soay.

D. cucubali Fuesl.
From Mingulay only, and not seen by us on any other island of the Hebrides; new, I believe, to the Outer Isles.

Charaeas graminis L.
On all the islands, including Mingulay and Berneray.

Luperina testacea L.
On Canna, Eigg, and Mingulay.

Celaena haworthii Curt.
A few on Soay only; taken flying with *Carsia imbutata.*

Apamea secalis L.
Common and of wide occurrence.

Miana strigilis L.
Abundant on Canna, Sanday, Eigg, and Soay in the form of the type and var. *ferrea* Warren.

M. fasciuncula Haw.
Canna, Eigg, Soay, and Mingulay with *pallida* forms.

M. bicoloria Vill.
Not uncommon on Rhum, Soay and Mingulay.

Xylophasia monoglypha Hufn.
Very plentiful on Eigg, Canna, Rhum, Soay, Berneray, and Mingulay with an abundance of var. *aethiops* Stgr. on the last two islands and Eigg.

Aporophylla lutulenta Bkh.
As var. *luneburgensis* Fr. on Eigg.

Polia chi L.
Typical specimens on Eigg and Canna; larvae on Rhum and Soay.

Euplexia lucipara L.
Larvae on Soay.

Hydroecia crinanensis Burr.
Common on Eigg, Rhum, Sanday, Canna, and Soay; rather rare on Pabbay.

H. lucens Fr.
The same range.

H. paludis Tutt.
Very rare, Eigg, Canna and Sanday.

H. nictitans Bkh.
A single specimen, (the only Hebridean example seen by me) from Soay.

H. micacea Esp.
Abundant on Ragwort; Eigg, Canna, and Soay; an odd example bred from a Mingulay pupa.

Stilbia anomala Hw.
A few in the northern half of Soay, and on Rhum.

Caradrina quadripunctata F.
Also common around Camas nan Gall, Soay.

Pachnobia rubricosa Fab.
Rufa and *pallida* forms abound on Coll and Eigg at sallow in spring.

P. leucographa Hb.
Once at sallow on Eigg.

Taeniocampa gothica L.
Forms ranging from var. *pallida* Tutt to *rufescens* Tutt, common on Eigg, rare on Coll, also larvae on Soay and Rhum. The var. *obsoleta* occurs on Eigg.

T. stabilis View.
In some variety on Eigg and Coll; vars. *pallida* Tutt and *rufa* Tutt prevail.

T. incerta Hufn.
Not common on Coll and Eigg; a magnificently mottled brown, buff, and white female was taken in the former island.

T. gracilis Fab.
One of the commonest Taeniocampids on Coll, also on Rhum and Eigg; vars. *pallida* and *rosea* Tutt cover the bulk of the population.

Omphaloscelis lunosa Haw.
Not at all rare in Eigg and Canna with var. *obsoleta* Tutt.

Xanthia lutea Strm.
Casually captured on Rhum and Eigg.

Anarta myrtilli L.
On Rhum, Soay, and Pabbay as larvae on the moors.

Calocampa exoleta L.
Rather common on Eigg.

C. vetusta Hb.
As with its congener.

Plusia chrysitis L.
Very rare on Soay.

P. interrogationis L.
On the moors on Soay.

P. gamma L.
Common in 1936 on Canna, Eigg and Sanday.

Abrostola tripartita Hufn.
Generally to be found whenever *Urtica dioica* grows on Coll, Eigg, Rhum, Canna and Soay.

Hypena proboscidalis L.
Likewise common and general on colonies of the common nettle.

GEOMETRIDAE.

Geometra papilionaria L.
On Rhum and Soay, but not common.

Acidalia aversata L.
Not previously reported from the Hebrides; found only on Soay.

Ephyra pendularia Cl.
Larvae sparingly on birch on Soay.

Ortholitha limitata Scop.
Eigg, Canna, Rhum, and Soay; much more typical than on Raasay.

Anaitis plagiata L.
Common on Soay; preparations made of genitalia confirmed its identification.

Carsia paludata Thnbg.
Abundant in one restricted locality near Loch Doire an Lochain, Soay, as var. *imbutata*.

Trichopteryx carpinata Bkh.
Eigg and Soay only, larvae on birch in the latter case.

Lygris testata L.
Common on Soay, Canna, Rhum and Pabbay.

L. populata L.
Not noted except on Soay.

Cidaria pyraliata Schiff.
Only on Eigg.

C. fulvata Först.
Not plentiful, but frequenting *Rosa Sherardi* forms on Soay, and *R. spinosissima* on Canna.

C. corylata Thnbg.
Common on Soay, Rhum, Eigg, Canna, and Pabbay.

C. truncata Hufn.
Plentiful, and very variable, on Coll, Eigg, Rhum, Canna, and Soay; scarce on Mingulay and Barra.

C. immanata Haw.
Common on Eigg, Sanday, Canna, Mingulay, and Pabbay; just appearing on Soay when we left.

C. miata L.
Larvae to be had everywhere on all the Inner Islands.

Thera variata Schiff.
Larvae of very sparse occurrence on spruce on Canna.

T. obeliscata Hb.
Larvae beaten from pine on Rhum and Eigg.

T. cognata Thnbg.
Scarce on Rhum.

T. juniperata L.
Larvae quite common on *Juniperus sibirica* on Rhum and Soay.

Coremia ferrugata Cl.
Common enough, apparently as a second brood, around the houses on Soay.

C. designata Hufn.
Also not rare on Soay; scarce on Canna.

Amoebe olivata Schiff.
Not rare on Eigg, Soay, and Pabbay.

Malenydris multistrigaria Haw.
Not at all rare Coll and Eigg.

M. didymata L.
Not so variable as on Raasay, occurs on Coll, Eigg, Rhum, Canna, Sanday, Soay, Mingulay, and Berneray.

Entephria caesiata Schiff.
Rare on Soay; the rarity of this insect in the Hebrides seems remarkable.

Xanthorhoe montanata Schiff.
One specimen on Mingulay.

Eulype hastata L.
On Soay, Eigg, Rhum, and Pabbay; not rare as larvae on *Myrica Gale.*

Mesoleuca ocellata L.
A few specimens on Soay.

Perizoma albulata Schiff.
Common around the harbour on Soay.

P. bifasciata Haw.
Rare with the preceding.

P. blandiata Schiff.
Plentiful on Ragwort on Central Soay.

Camptogramma bilineata L.
Very common, especially vars. *infuscata* Gmpg. and *atlantica* Stgr., Coll, Eigg, Rhum, Canna, Soay, Pabbay, Barra, Berneray, and Mingulay.

Hydromena trifasciata Bkh.
Larvae beaten from alder on Rhum, near Kinloch Castle, Eigg, and on Pabbay.

H. ruberata Fr.
Larvae everywhere common on *Salix aurita* on Canna, Rhum, and Soay.

Eupithecia oblongata Thbg.
At Ragwort on Soay.

E. pulchellata Stph.
Larvae on *Digitalis purpurea;* Canna, Rhum, Soay, and Pabbay.

E. venosata Fab.
Scarce, larvae on *Silene maritima* Soay and Canna.

E. absinthiata Cl.
Scarce on Soay, larvae on Pabbay.

E. goosensiata Mab.
Larvae on Coll, Soay, Eigg, Canna, and Rhum.

E. castigata Hb.
On the same islands as the preceding.

E. lariciata Fr.
Rare on larch on Rhum only.

E. helveticata Bdv.
On Mullach Mor, Rhum, on *Juniperus sibirica.*

E. satyrata Hb.
As with *E. castigata.*

E. nanata Hb.
Everywhere on heather on all the islands.

Abraxas grossulariata L.
In great numbers and always on *Calluna* on Eigg, Rhum, Canna, Soay, Pabbay and Barra; the species varies but little on these islands.

Cabera pusaria L.
On all the Inner Islands.

C. exanthemata Scop.
Displays the same distribution as its congener.

Epione apiciaria Schiff.
Somewhat rare on Eigg.

Metrocampa margaritaria L.
Not common on Rhum and Soay.

Selenia bilunaria Esp.
Larvae not rare on birch and sallow on Soay and Eigg. The sallow feeding larvae are very pale forms.

Gonodontis bidentata Cl.
In spite of special effort to get it, this species turned up on Eigg only.

Crocallis elinguaria L.
On heather on Rhum and Soay.

Opisthograptis luteolata L.
As very large strongly marked examples flying in August on Rhum and Soay; larvae on Eigg.

Nyssia zonaria Schiff.
Larvae and imagines extremely abundant on Coll; larvae also in thousands on Canna, Sanday, Barra, and Mingulay. Wherever possible *Iris Pseudacorus* was the favourite food plant although

on Sanday *Centaurea nigra* ran it a good second. On Canna, the species occurred from sea-level to the top of the cliffs on the moorlands. Racially, the insects are quite distinct from English forms, for they are only two thirds the size and distinctly darker in the majority of cases. I call them race *atlantica*.

Amphidasys betularia L.
Larvae on birch on Soay and Eigg.

Boarmia repandata L.
Fairly common on Canna, Rhum, Eigg, and Barra; the grey *sodorensium* Weir form predominated.

Gnophos myrtillata Thnbg.
Larvae on heather on Barra.

Ematurga atomaria L.
Larvae on Coll, Rhum, Eigg, Canna, and Soay.

Bupalis piniaria L.
Common on pine near Kinloch Castle, Rhum; also on Eigg.

ZYGAENIDAE.

Zygaena filipendulae L.
Not very common along the coast of Rhum north of Kilmory.

HEPIALIDAE.

Hepialus sylvinus L.
Quite rare on Soay around the eastern harbour.

GALLERIADAE.

Aphomia sociella L.
Rather common on Eigg.

CRAMBIDAE.

Crambus pascuellus L.
Eigg, Canna, Rhum, Soay.

C. ericellus Hb.
Soay and Rhum on the moorlands.

C. pratellus L.
Not rare, Eigg, Canna, Rhum, and Soay.

C. culmellus L.
Common on the same islands as well as Soay.

C. pinellus L.
Rhum and Soay.

C. margaritellus Hb.
Not abundant on Eigg, Rhum, Canna and Soay.

PYRAUSTIDAE.

Hydrocampa nymphaeata L.
Plentiful around Loch Mor, etc., Soay.

Phlyctaenia lutealis Hb.
Common on Eigg, Canna, and Soay.

Pyrausta aurata Sc.
Rare on Soay.

Scoparia ambigualis Tr.
Found on all the islands.

Mesographe forficalis L.
Common on all the Inner Islands including Pabbay.

PTEROPHORIDAE.

Stenoptilia bipunctidactyla Hw.
Rare; on Soay only.

Eucosma dimidiana Sodof.
Common on all the Inner Islands, save Soay.

Epiblema penkleriana F.R.
Generally distributed.

E. pflugiana Hw.
Not rare, Soay, Rhum, Canna.

E. solandriana L.
Also common on the same islands.

TORTRICIDAE.

Acalla hastiana L.
On all the islands south of Skye.

A. sponsana F.
Not uncommon on Eigg.

Cacoecia podana Sc.
A few on Soay.

GELECHIADAE.

Gelechia ericetella Hb.
Common and well distributed.

Depressaria nervosa Hw.
Rhum, Canna, Soay and Pabbay; common.

D. heracliana L.
Rhum and Canna; not common.

D. applana F.
Coll, Rhum, Canna and Soay; common as larvae on the last three, and as imagines on Coll.

Acompsia pseudospretella St.
Soay only.

ELACHISTIDAE.

Coleophora viminetella Z.
Plentiful everywhere.

C. limosipenella Dap.
Rhum, Soay, Canna.

C. laricella Hb.
Rare, Rhum only.

C. discordella Z.
On *Lotus* in cliff cracks in southern Soay.

C. caespititiella Z.
Exceedingly abundant everywhere, even on Pabbay.

PLUTELLIDAE.

Simaethis fabriciana L.
Common wherever nettles grow.

TINEIDAE.

Lithocolletis viminetorum St.
On Soay.

Gracilaria elongella L.
Also only detected on Soay.

Argyresthia goedartella L.
Also only on Soay.

A. conjugella Z.
Taken on Rhum, Canna and Soay.

Tinea cloacella Hw.
A few on Eigg.

LINTON MIRES, WHARFEDALE.

Glacial and Post-Glacial History. Part I, Physical.

A. Raistrick, Ph.D., M.Sc., F.G.S.

Linton Mires occupies the curious through valley running between Grassington in Wharfedale and Skipton in Airedale, lying between the hill masses of Burnsall and Barden Fells to the south and the Threshfield and Winterburn Moors to the north. The valley which can be referred to as the " Cracoe Gap," runs south-west with a low col near Cracoe, at 630 ft. OD. The Wharfedale end of this valley is blocked by a great accumulation of material, mainly morainic debris, behind which was impounded a series of lakes, the site of which constitutes the Linton Mires, now a flat area of alluvium and peat, 1¾ miles long and over ½ mile wide. The history of this lake series starts during the retreat stages of the Wharfedale glacier, and is continued by deposits of clay and peat until fairly recent times.

At the maximum of the glaciation of west Yorkshire, the ice sheets covered all but a few of the highest summits in this area (1), and it was not until the separate glaciers of Airedale and Wharfedale were well established that the Cracoe valley began to play an important part.

As the Airedale glacier shrunk from the maximum position of its ice edge, lateral drainage along the northern edge, and from west to east along the breast of the Malham to Settle fells, made its way by a series of lateral and watershed overflow channels into the Winterburn valley west of the Cracoe gap. The mouth of this valley was blocked by the edge of the Airedale glacier and a lake, impounded in the upper part of the valley, was only able to overflow at a succession of points across the low ridge between it and the Cracoe valley (2, and see fig 1). A series of four well-marked overflow channels remain at levels approximately 950 ft. OD., 730 ft. OD., 690 ft. OD., and 600 ft. OD., corresponding with four retreat positions of the Airedale glacier. The Wharfedale glacier at the same time abutted

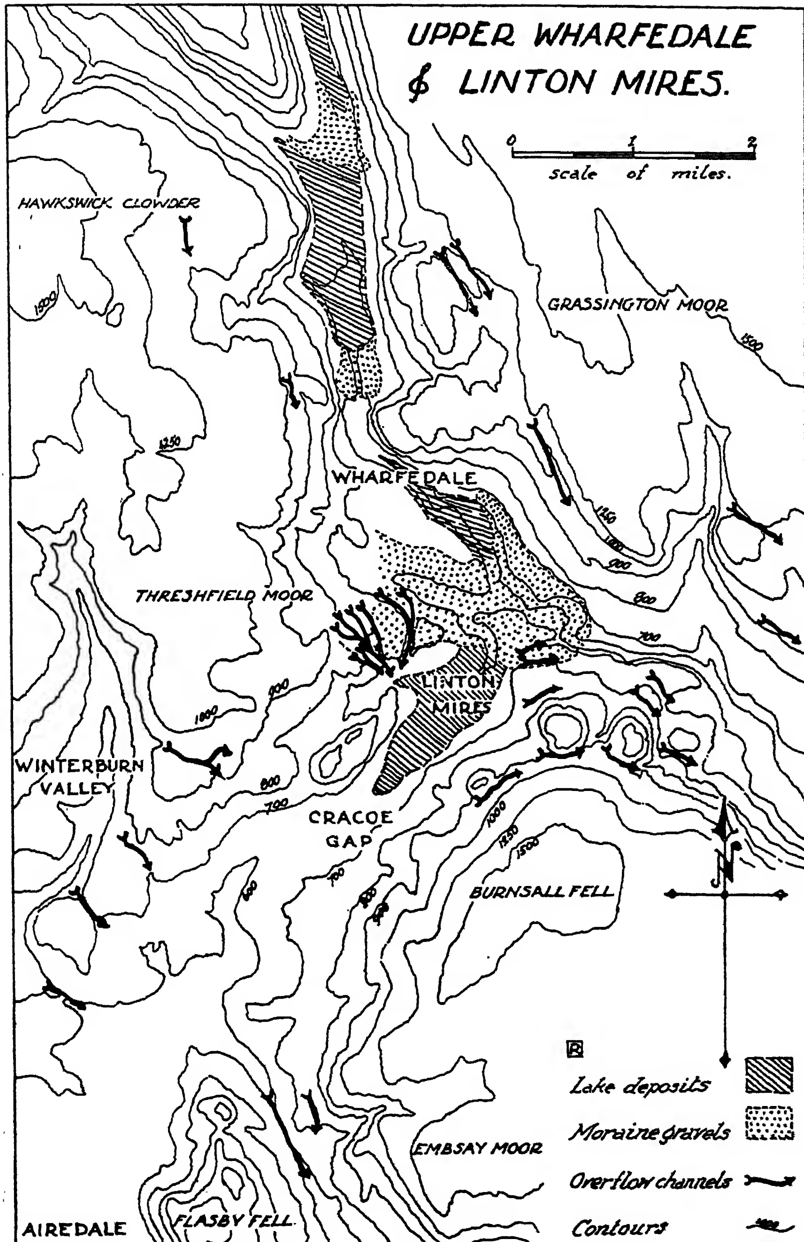
UPPER WHARFEDALE & LINTON MIRES.
0 1 2
scale of miles.
HAWKSWICK CLOWDER
GRASSINGTON MOOR
1500
1250
WHARFEDALE
THRESHFIELD MOOR
LINTON MIRES
WINTERBURN VALLEY
1000
900
800
700
CRACOE GAP
BURNSALL FELL
EMBSAY MOOR
AIREDALE
FLASBY FELL
Lake deposits
Moraine gravels
Overflow channels
Contours

Fig. 1.

against the northern shoulder of Burnsall Fell and effectively closed the Linton end of the Cracoe valley. Lateral drainage of the southern flank of the Wharfedale glacier was brought into the Cracoe valley at the north-west corner by a series of channels from 900 ft. OD. to 690 ft. OD. level. As the south end of the Cracoe valley was blocked by the Airedale ice, a lake was impounded between the fells north-west and south-east, and the ice barrier at each end. The earlier of these lakes overflowed by channels along the ice edge, round the north shoulder of Burnsall Fell, the highest (an earlier stage than the definite channels just described) at 970 ft OD. between Butterhaw Hill and the Fell shoulder, continued by shelf channels and by the cols behind Elbolton and Kail Hill, on to the side of the Wharfe valley. This corresponds to a lake position higher than the first Winterburn valley channel, when the whole Winterburn area was still occupied by ice. The drainage of the later positions of the lake level was by channels, sometimes around Embsay Fell edge into Airedale, at other times along Burnsall Fell shoulder into Wharfedale. Well established lake positions were marked by overflows southward at 720 ft. OD. and north-eastward at 680 ft. OD. and 620 ft. OD.

After the 680 ft. OD. position, the col near Cracoe became a dry barrier, so that the lake retreat stages following, are marked by separate and independent lakes in the two ends of the valley. It is here that Linton Mires begins its separate existence.

The 680 ft. OD. lake position is intimately connected with the series of overflow channels across the shoulder of Threshfield Moor, which converge on the mouth of Millstone Gill (see fig. 2). Here at the point where the gill opens into the Linton Mires area, are portions of a delta well displayed on each side of the present small stream, with a level surface at 680 ft. OD. Connected with this delta position are five channels, a first high-level pair, converging on one main channel, and three lower ones, joining the same mouth near the delta, and formed at about 30 ft. (vertical) intervals as the ice-edge shrank down the slope of the main valley. During all this time, the Wharfedale glacier impinged

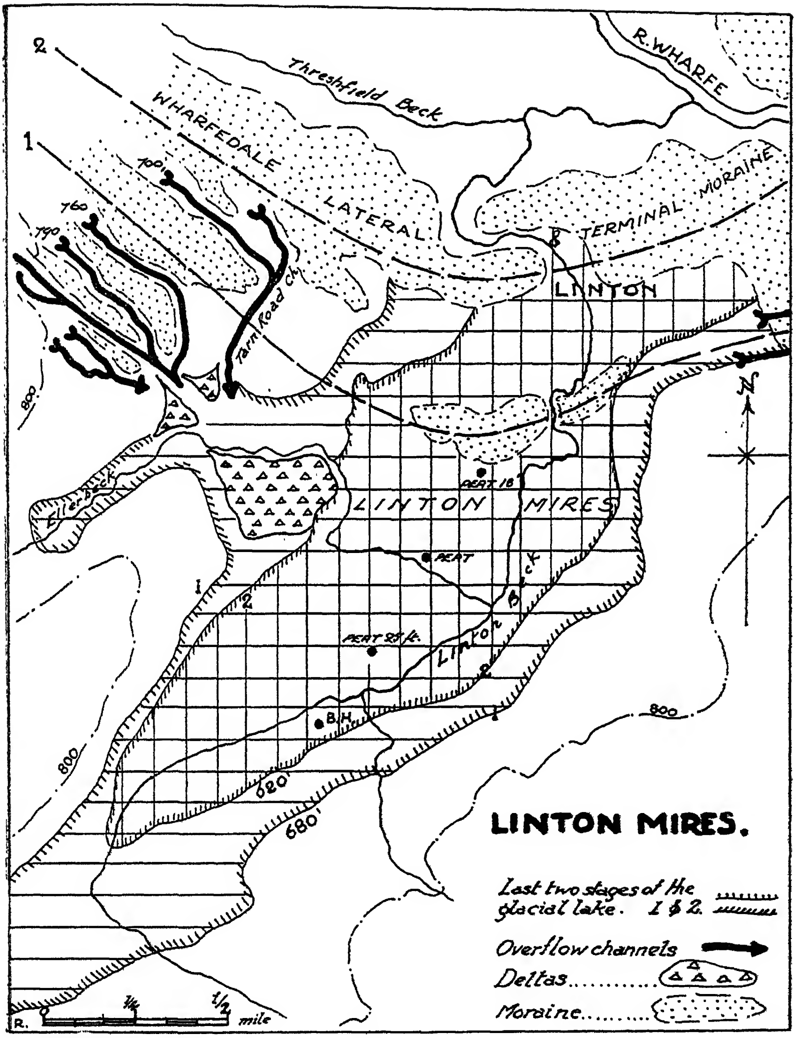

Fig. 2.

directly on to the shoulder of Burnsall Fell and was deflected by that, down the main valley. This position is marked by high lateral moraine ridges along Threshfield Moor edge and by a crescentic moraine, convex to the south, across the mouth of the Cracoe valley (position 1 of fig. 2). The crest

of this moraine stands out above the Mires as high ground and a gravel ridge, through which Linton Beck has cut a narrow gap. To the east the ridge is continued by a series of high gravel mounds and residual ridges running round the base of Elbolton and reaching the Wharfe below Stickhaw Hill, between Linton Church and Hebden.

With further slight retreat of the Wharfe glacier, a lateral-terminal moraine was formed between the first one and the river, which is much bigger and better preserved, forming a marked feature of the present topography. The lateral part of the moraine runs along the valley side south of Threshfield at about 700 ft. OD. and begins to swing round as a crescentic moraine through Great Bank and the high gravel ridges between Linton village and the river. This moraine crosses the river valley between Linton Mill and Grassington Bridge, the river having cut through it on to solid rock floor. Sections of this moraine are seen in many gravel and sand pits in the area, and it is the chief source in the district of the numerous boulders of Silurian grit presumed to have come from the floor of the Wharfe valley near Kilnsey Crag.

During the deposition of this moraine, the lateral drainage along the Threshfield Moor edge cut the big double-headed channel now used by the Skipton-Threshfield Road (Tarns Lane), at 695 ft. OD. at the col through the ridge. At the mouth of this channel is the largest delta of the series, that at Lauradale Bridge, around which the present Ellerbeck is deflected (fig. 2). This delta has a strikingly flat top at 640 ft. OD. This marks the level of a glacial lake fed by the Tarns Lane channel, and draining round the Burnsall Fell shoulder into Wharfedale below the moraine. After the retreat of the ice from this position, the lake remained as a more or less permanent feature, impounded no longer by the ice edge, but by the morainic barriers near Linton. During the subsequent post-glacial periods the lake was gradually silted up or choked by peat growth, finally producing a level peat and alluvium surface at 620 ft. OD. The Linton Beck, running over this surface is deflected north-west through a narrow gap in the moraine (probably determined in position

by original depressions in the moraine surface allowing overflow at that point when the ice had finally retreated) into the valley of the Threshfield Beck, which runs first north-east, then due east between two ridges of the moraine, to join the Wharfe. This gap is still very immature, the stream falling 25 ft. in 400 yards, as against 20 ft. in the preceding 1½ miles.

This large area of alluvium is known as Linton Mires, and its deposits have been examined both by boring and excavation. The floor of the Mires is formed of a deep calcareous silt and clay with marly beds that have occasionally been dug near the margins of the Mires. At many places around the Mires, long spits of gravelly hill-wash run out into the finer silts. The clay is covered by a varying depth of peat, which has been examined at four points marked on the map fig. 2. At various times in recent years, attempts have been made to ascertain the depth of the peat, and its suitability for cattle bedding or for fuel, and small amounts have been dug. At the northern point, an excavation to 18 ft. depth showed a top spit of gravel, with peaty soil and finer gravel below, resting on soft black peat. Several hazel twigs and nuts and fragments of wood were taken from the peat.

At the second point, the gravel cover was again found resting on peat, but the peat was too water logged to be cut. The third point was excavated to 25 ft. depth and again soft black peat was seen beneath a thin cover of gravel, but its base was reached, resting on fine grey clay. Towards the top of the peat, thin spits of sand and gravel marked the latest silting of the lake area. At the southernmost point, a boring was put down in 1936 and peat cores obtained to 3 metres depth. It is clear from the map that this site is much nearer the edge of the Mires, than the other three positions. This was necessary to avoid the cover of gravel, through which it was found impossible to drive the peat borer. In addition to these main excavations, frequent shallower sections for drainage have been seen, and enough observations made to make clear the physical history of the Mires.

The lowest material seen in any of the cuts, and seen at the base of the basin all round its shallower parts, is a coarse

grey silt, passing upward into finer grey clay, silt, and marl, with gravel near the edges, and at the mouth of the feeding glacier channels. These deposits all represent the silt carried and deposited by the glacial melt water drainage, and provided from the englacial material of the melting ice and from the cutting of the drainage channels. With the further retreat of the ice and establishment of the moraine dammed lake, silting became almost negligible, and peat accumulation began. After a considerable period peat growth had converted the area into swamp, with some tree growth, when change in climate and possible uplift of part of the land, resulted in renewed stream activity and the accumulation of silts and gravels on top of the peat.

Peaty and swampy conditions were occasionally renewed and through historic time, the area remained mainly swampy with occasional flooded periods. Much of the change from water drowned swamp to drier peat area, must have been linked up with the remarkable re-excavation of the Wharfe valley through and below the moraines at Linton. From Linton Mill southward for three miles, the Wharfe at present runs through a narrow gorge, with steep boulder clay sides rising to a gently sloping wide valley floor, almost everywhere of boulder clay. At Linton Mill there are the Falls where the river has cut down to a ledge of limestone, but below that point, solid rock is not again seen until nearing Burnsall. This gorge is cut about 150 ft. below the drift filled valley floor, and the re-excavation may have been fairly rapid until checked by the solid ribs at Linton Falls and above Burnsall. During this period of re-excavation, the tributary stream of Threshfield Beck and Linton Beck, would be rapidly rejuvenated, and able to cut back against the moraine front more and more vigorously. This was probably the period of the first breaching of the moraine, followed by a fairly rapid drop in lake level. The lower part of Linton Beck has re-excavated its course nearly down to river level, and the steep fall is now mainly within the moraine gorge at Linton. As this cuts back, and lowers its lip (about at Linton village, now) the water table of the Mires will be still further lowered, and the land still further reclaimed. This process has been helped in

recent time by some amount of deep drainage. In the seventeenth century the area is referred to by topographers as Linton Tarn and Linton Mere, but in the eighteenth century, while occasionally entirely flooded and under water, part was drained and brought within the Enclosure award for the village of Linton. The final drainage and enclosure, with subsequent conversion to rough pasture and partly to wet meadow, was accomplished during the first half of the nineteenth century. There is considerable historic evidence that for a few centuries now, the area has been naturally "drying out," quite apart from the drainage that has been done to improve the surface. The peat boring obtained in 1936 has been examined biologically by Dr. Blackburn, and is described in the second part of this paper.

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LINTON MIRES, WHARFEDALE.

Glacial and Post-Glacial History. Part II, Biological.

Kathleen B. Blackburn, D.Sc., F.L.S.

Introduction.

Dr. Raistrick has shown in his study of the glacial features of the area, that a lake was originally produced by the holding up of melt-waters in the connecting valley between the Aire and Wharfe Glaciers. Various overflow channels indicate a gradual lowering of level which subsequently isolated the Wharfedale end of the lake. This lake did not drain completely when the ice finally retreated, because the Wharfe Glacier left a series of moraines across the valley. Linton Mires has thus an unusually long history as a lake. Dr. Raistrick suggested that it might be interesting to study the peats, to see if biological evidence would support the conclusions derived from a study of physical features.

The area has been drained and consists, at present, of rushy pasture with small sedges in some areas. From local evidence it is known that in some places there are 24 ft. of peat but, in one portion indicated, the boring tool could not be used owing to a thick seal of stiff marly clay lying on the top of the peat. Towards the south-west end of the area, at the spot marked B on the map in fig. 2, the peat reaches the surface and was found to be about 3 metres thick. The top layers of peat were removed from this locality about 60 years ago and the description of the stripping, by the man who actually did it, suggests that the surface was covered with tussocks of *Molinia* (Blue Moor Grass) and under them was raw *Sphagnum* peat which was used for bedding. A much longer history will be possible if opportunity offers to work the deeper peats, but the results already obtained are so definite that it seems worth while to publish them as they stand, as an amplification of the geological record.

Sources of Evidence.

In considering deposits of this type there are three main methods of obtaining evidence:

a. A study of the character of the deposit itself including the nature and succession of the different layers present both in the peat and the underlying sediments.

b. The identification of the remains of indicator organisms such as fruits or seeds, leaves of mosses, fragments of wood, rhizomes of *Phragmites* and *Eriophorum* (Cotton Grass) or the shells of mollusks.

c. Pollen investigations. The nature of the surrounding forest is given by the tree pollen and that of the immediate vegetation by the pollen of sedges and heaths or the spores of *Sphagnum* and ferns.

Summary of the Data.

A graphical illustration of the finds from the three sources mentioned above is given in fig. 3. The indication of the type of deposit, shown in the first column, is self-explanatory. The vertical distribution of some indicator organisms is next seen, with the relative quantities at different depths suggested by the width of the black band. The Characeae, *Menyanthes* (Bogbean), *Ranunculus aquatilis* agg. (Water Buttercup) and *Potamogeton* spp. (Pondweeds) were present as fruits or seeds. The species of *Hypnum* appear as leaves or fragments, in most cases in such a condition that it is clear that they were washed up on the edge of the lake, just as were the shells of the shell marl. The algae, *Botryococcus* and the desmids, are recognizable as skeletons; the other plants whose distribution is figured were seen as pollen or spores. The sedges alone were represented under two categories; the figure is chiefly based on pollen counts but it is extended at the lower end where no pollen was preserved with the aid of fruits.

The third section of the diagram shows the results of the tree-pollen counts, recorded graphically in the usual way, *i.e.*, the pollen of the various trees is expressed as a percentage of the total tree-pollen counted, excluding the hazel and willow. These last are calculated separately as a percentage of the tree pollen, and it will be noticed that the hazel often gives percentages much over 100 per cent, which represents an excess of hazel over everything else. The two circles give " spectra " representing the relative quantities of the pollen of different

trees in the top three samples, and in the remainder, respectively.

Detailed Results and Deductions.

From the evidence brought forward two sets of information can be obtained: the first refers to the purely local development of the locality, including its ecology, and the second correlates it with a wider forest succession and so enables us to date the levels in relation to other post glacial events in north-west Europe.

Ecological Development.

If the deposit is followed upwards, layer by layer, a fairly detailed picture of the ecological changes can be obtained.

At the base of the bore the sample looked like a normal lake-bottom clay, chiefly of a grey tint, but investigation showed that it had a high calcium carbonate content. This might well be expected in a locality just below the Cracoe limestone outcrops. In this marly clay were found, to the lowest depth examined, fruits of the Stoneworts (Characeae), representing at least two species. The quantities of the fruits were small and there was very little other organic matter. Taking all the factors into consideration there is a suggestion of a fairly rapid deposition of the finer particles in relatively still water.

At a depth of 3¼ metres the character of the deposit changes and becomes much coarser, suggesting a much more rapid movement of the water at the point. At 3 metres and above, almost to the 2 metre level, the layers showed quantities of moss fragments, seeds, and fresh-water shells which were clearly detritus deposits at the margin of a lake, and, presumably, the end opposite that of the prevailing wind. The mosses were chiefly species of Hypnum but the association of species changed at different levels. *H. stramineum* Dicks. was present at all depths indicated on the diagram; *H. falcatum* Brid. and *H. Schreberi* Willd. were in quantities in the lowest layers; next *H. fluitans* L. appears. Above, the first two vanish to be replaced by *H. giganteum* Schp. *Webera nutans* Hedw. was only seen at the level of the first appearance of *H. fluitans*. The mixture of submerged and shallow water species is explicable if all, or some, are washed-up fragments from some other part of the lake.

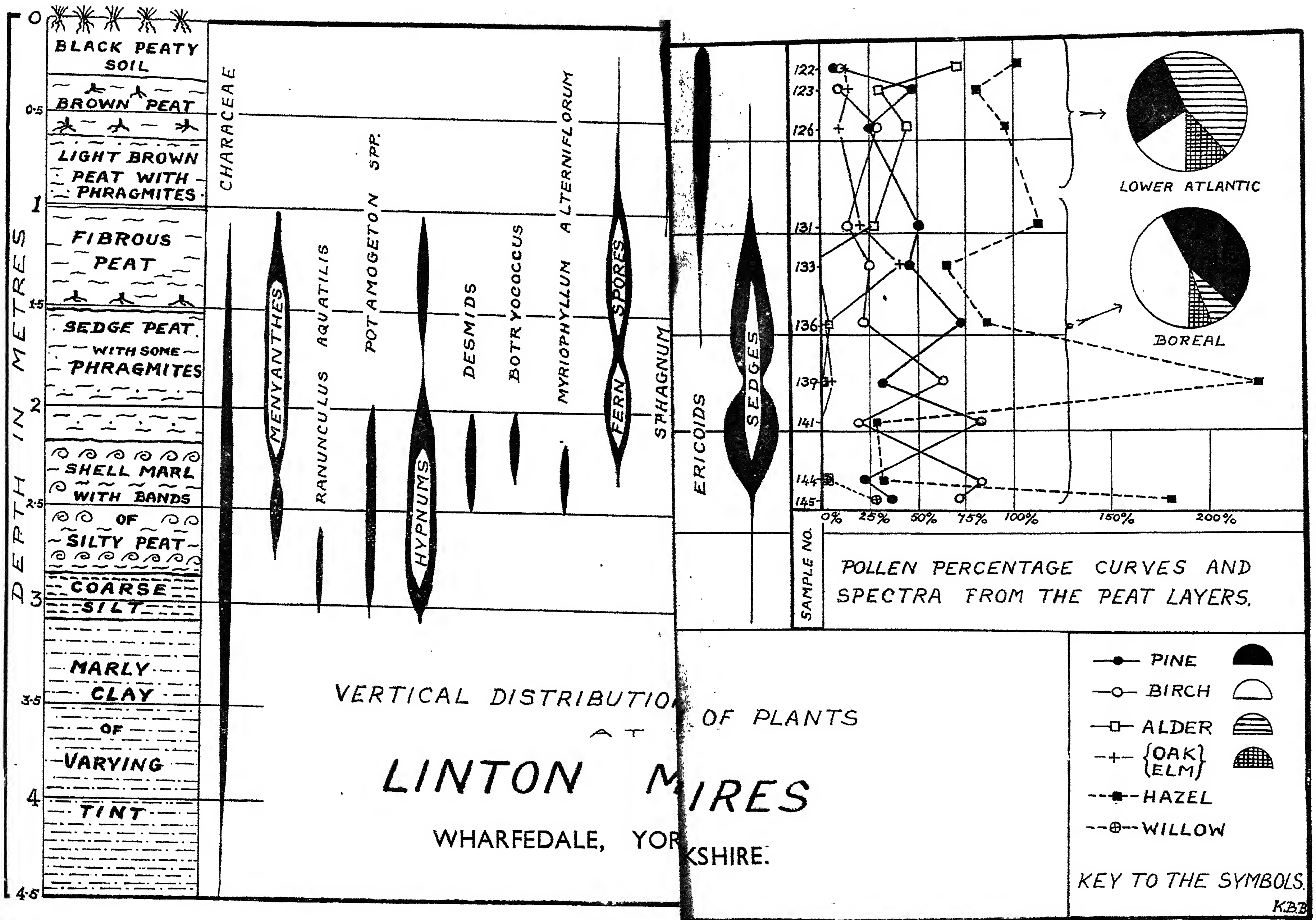

DEPTH IN METRES
0
0·5
1
1·5
2
2·5
3
3·5
4
4·5
BLACK PEATY SOIL
BROWN PEAT
LIGHT BROWN PEAT WITH PHRAGMITES
FIBROUS PEAT
SEDGE PEAT WITH SOME PHRAGMITES
SHELL MARL WITH BANDS OF SILTY PEAT
COARSE SILT
MARLY CLAY OF VARYING TINT
CHARACEAE
MENYANTHES
RANUNCULUS AQUATILIS
POTAMOGETON SPP.
HYPNUMS
DESMIDS
BOTRYOCOCCUS
MYRIOPHYLLUM ALTERNIFLORUM
FERN SPORES
SPHAGNUM
ERICOIDS
SEDGES
SAMPLE NO.
122
123
126
131
133
136
139
141
144
145
0%
25%
50%
75%
100%
150%
200%
LOWER ATLANTIC
BOREAL
POLLEN PERCENTAGE CURVES AND SPECTRA FROM THE PEAT LAYERS.
VERTICAL DISTRIBUTION OF PLANTS AT LINTON MIRES
WHARFEDALE, YORKSHIRE.
PINE
BIRCH
ALDER
{OAK ELM}
HAZEL
WILLOW
KEY TO THE SYMBOLS.
K.B.B.

Fig.

The following fresh-water mollusks were found in layers in this part of the deposit and are listed in order of frequency:—

Planorbis laevis Ald.
Bithynia tentaculata Linn. (Opercula).
Limnaea pereger (Müll.)
Pisidium nitidum Jeff.
Pisidium milium Held.
Valvata piscinalis (Müll.)
Valvata cristata Müll.
Planorbis complanatus (Linn.)
Planorbis crista (Linn.)
Ancylus lacustris (Linn.)

A number of very small specimens of a Copepod, tentatively named by Mr. Lowndes *Candona candida* (O. F. Müller), accompanied the shells. Besides the fruits of *Ranunculus* and *Potamogeton* others occurred in small numbers, among which may be mentioned *Eleocharis palustris* and *Scirpus lacustris*.

By the time represented at the 2½ metre level, shallow water plants were beginning to root there, as is indicated by the large number of seeds of *Menyanthes* (Bogbean). Here also the deposit contained algae characteristic of lake margins, such as desmids of the genus *Cosmarium*. At least five species of this genus were seen, but only two, *C. Botrytis* Menegh. and *C. granatum* Bieb., were able to be named with certainty. Two other algae, *Pediastrum Boryanum* and *Botryococcus Braunii*, were found in these layers.

Between the 2 and 1 metre levels the shallow edge of the lake became transformed into fen. Sedges, ferns, including *Lastrea Thelypteris*, *Phragmites* and *Menyanthes* were all present. The roots of willow and some birch wood were found here, as well as higher up.

At about the ½ metre level the plants appear to have changed. The last sign of *Phragmites* was just below this level. Slides prepared to show pollen exhibit a conspicuous decrease of fern spores and sedge pollen; on the other hand ericoid tetrads and *Sphagnum* spores are in increasing amount. The vegetation, now raised above the level of standing water,

has taken on the character of *Sphagnum*-bog. Though there is only a very thin layer left to prove it, the local development of a raised-bog (Hochmoor), with its domed top, may have been the cause of the failure of the floodwaters of a subsequent rainy period to cover it with the layers of marly clay or gravel found elsewhere on Linton Mires. Drainage, as well as the stripping referred to above, may account for the very small quantity of *Sphagnum* peat that remains. Only one species of the moss has been identified. This is *Sphagnum imbricatum,* which is readily distinguished by its leaves. This species is somewhat rare in our country to-day but the author has found it to be the dominant moss in the *Sphagnum* peats of "Mosses" further west, as at Lindow Moss, Cheshire, and Chat Moss near Manchester, though recent draining seems to have killed it off in these places.

The botanical evidence, in relation to the part of Linton Mires at which the bore was taken, can now be briefly summed up: The first appearance is of the still waters of a lake in which little was growing but a few Stoneworts, then rather suddenly, the level of the water fell and our area is at the margin of the lake. Silting up continued, but now no longer with mineral particles alone, for these are gradually completely replaced by organic fragments, including seeds and shells. In the shallow margin plants began to root, and various phases of fen vegetation are to be recognized. After the fen phase one of *Sphagnum*-bog is indicated but most of this has been removed and there is nothing left but rough pasture.

The Date of the Deposit.

The pollen-statistics give clear indications of the date of this peat. Investigation of the tree-percentage graph shows that the lower part has the features characteristic of the Boreal Period when, with the final disappearance of the ice, a warm continental climate supervened and the characteristic trees which invaded the land were Pine, Birch and Hazel. Late in this period mixed Oak forest, here represented only by Elm and Oak, made its appearance. With increasing rainfall the Alder, already present in small quantity, rapidly gained

ground. The point at which a falling Pine curve crosses a rising Alder line is defined as the end of the Boreal and the beginning of the Atlantic Period. The spectra drawn from below this crossing, and above, therefore represent Boreal and Early Atlantic spectra respectively.

The Boreal spectrum is almost identical with one drawn from Erdtmann's curves for Chat Moss (Erdtmann 1929, Raistrick and Blackburn 1931).

The lower Atlantic spectrum differs from that of Barden Fell, a hill-top peat in the near neighbourhood, only in the higher Pine and lower Birch. This may possibly be correlated directly with altitude, since this is at 620 O.D. and Barden Fell at 1460 O.D. (See Raistrick and Blackburn 1932). A much closer comparison is with an early Atlantic Spectrum for mid-west Scotland figured on a map with spectra of this date. (Godwin 1934, p. 355). From these conclusions it seems likely that a considerable quantity of peat has been removed from the surface at the point where the bore was sunk. We have thus the unusual spectacle of grass growing directly on an undisturbed early Atlantic peat.

An examination of the mollusks found in the shell marl gives confirmation of an early date for the peat. The large proportion of *Planorbis laevis* is considered by Mr. Kennard to be characteristic of Boreal deposits but since he comments that these snails were small and stunted, it is to be assumed that their date was before that of great improvement of climate, and so, early Boreal. This would agree with their position in relation to the peat deposit, but Mr. Kennard makes it quite clear that the shells do not indicate the earlier arctic conditions.

Acknowledgments.

My grateful thanks are due to the following for help in various ways: The King's College Research Grants Committee for grants for apparatus; Mr. A. S. Kennard for naming the Gastropod snails and for helpful comments and data on other snail records; Mr. Charles Oldham for similar kindness in connection with the Pisidia; Miss Evelyn Lobley for identifying the mosses; Dr. Nellie Carter for examining the Desmids and Mr. A. G. Lowndes for naming the Ostracod.

MILL CLOSE MINE, DERBYSHIRE, 1720—1780.

A. Raistrick, Ph.D., M.Sc., M.I.Min.E.

Although Mill Close is one of the best known lead mines in Britain, very little has previously been known of its history prior to 1860, beyond the fact that for a period in the eighteenth century it was worked by a company of Quakers. Mander's Mining Glossary (1824) says, "About the year 1743 the Quakers' Company, as it was then called, purchased Mill Close Mine in the Liberty of Wensley . . . upon which they not only erected a fire engine to draw water out of the mine, but also built coes, etc. They likewise wrought a sough, or water gate, without having a vein, into Birchover Lordship, and diverted a brook or water course, down such for the purpose of turning a water-wheel, which they had in this said mine." Farey (General View of Agriculture and Minerals of Derbyshire, vol. i, 1811, p. 385, says, "The *Cupolas* or low-arched Reverberatory Furnaces, now exclusively used for the smelting of Lead-Ore in Derbyshire, were introduced from Wales by a company of Quakers, about the year 1747, the first of which was erected at Kelstedge, in Ashover." These two are about the only precise references there are to the Quaker Company at Mill Close. During work in recent years on the minute books, etc., of the London Lead Company, popularly called the Quaker Company (see Raistrick, London Lead Co., 1692-1905, *Trans. Newcomen Soc.,* xiv, 1934, pp. 119-163, for fuller account), the main dates and reports of working in Derbyshire, were obtained, and these have been considerably supplemented recently by the receipt from Mr. J. H. Shield of Burnlaw, Allendale, of a large bundle of papers and leases relating to this company's work in Derbyshire. It is now possible to give a fairly complete documented account of the Mill Close mine as one of the central properties of this company.

In 1720, the L.L.Co. heard of lead mines in Derbyshire, and after enquiries and visits by two of the members of the company, from their lead mines in Flint, the company

decided to take up several leases. On the 13th September, George Greaves, brother of the Duke of Rutland's mine agent in Derbyshire, was instructed to take up, acting through and with the advice of his brother, a lease of 100 meres of ground along three separate veins, which had been proved good by previous working, and to register these in the Barmaster's books, paying 12d. per mere for registration. The " mere " is measured along the length of a vein, in this part of Derbyshire, being 29 yards, and it includes the use of a distance to each side of the vein of 7 to 8 yards, to provide room on which to work or erect buildings. Thomas Greaves was appointed to act as agent for the company, being responsible to Thomas Barker, the manager at Flint, N. Wales. The mines taken lay near the River Derwent in the parishes of Wensley and Winster, near Ashover. In 1721 three members of the Court of the Company made their report on an inspection of the mines, and gave a wealth of detail of shafts and trial holes made and making. The original leases along the three veins had been extended, and new ones added, so that more than a dozen veins are reported on. The average depth of the shafts being re-opened is about 30 fathoms, and the quantity of water encountered is urged as a good reason for " bringing up a sough," i.e., driving a drainage level from a low point on the river side.

This was soon started, and a report in April 1722 says—

" The Co., etc., are undertakers of several old works in Bank Pasture pa. Winster, as follows—

Longtor Old Vein, E-W. 21 meres.
Longtor Gate Vein, NW-SE. 16 meres.
Land Vein N-S. 18 meres.
Delfe Vein N-S. 18 meres.
Horse Hay Vein, N-S. 24 meres.
Accow Stool Vein 10 meres.
Barton Stool Vein 8 meres and crosses Delfe Vein.
Clark Old Vein, NW-SE. 24 meres.
Sellory Langtor Vein 36 meres.
Longtor Steele Vein, N-S. 12 meres.

Taken in Sept. 1720 by Geo. Greaves and sold to the Co. Stand unwrought by reason of great cost of bringing up a Sough which is now in constant workmanship and will unwater all these veins at their deepest Soles which have stood in water of several fathoms for many years now."

In Sept. 1723 the visitors report that the drainage sough has been driven up 100 fathoms and is going forward, and ten veins are now at work and producing ore. The work progressed steadily, ore being sold to local smelters, or transported to Flint, until 1734, when the Company decided to smelt locally. For this purpose, Bowers' Smelt Mill, in Ashover, was leased for 21 years, the lease being renewed in 1755 for 15 years and again in 1770 for 21 years, but was surrendered in 1778. Between 1735 and 1737, the Company took out the existing furnaces and built new ones of their own type, the reverberatories referred to by Farey. Local masons were employed but each had to enter into bond in £100 to the Company

"not to build or by any means or methods to Direct the Building or Erecting any the like ffurnace or ffurnaces for the space or term of Twenty years next ensuing, for or for the Use or Benefitt of any other Person . . . etc. . . . save only for the above named Governor and Co. . . . etc."

The bonds recite that the masons have no knowledge how such a furnace works or is made, and they shall be instructed fully by Joseph Whitfield, the Company's secretary and manager in Derbyshire.

Among the few papers relating to the further history of the smelt mill are several leases and agreements for wood and coal for fuel, and a note in 1774 that the furnace is not at present employed more than 26 weeks in the year.

The mines in Winster and Wensley were continued and the sough pushed forward, with varying success, but by 1741 the works were approaching the line of old workings on the Mill Close vein, half a mile west of the river, and it was decided to purchase this mine. The purchase was completed 8th Jan., 1742/43, between Joseph Whitfield and Thomas Westgarth, for the Company and Stephen Bagshaw, Barmaster, acting for the old partners (14 in number) for £1,050. In the next year, the level already driven through some of the Company's veins was carried forward and cut the Mill Close vein, being now called the Mill Close Low Level. Watering Close vein was being worked further to the west and parallel to Mill Close vein, and the level was carried forward toward

it with the idea of unwatering a rich complex of veins immediately west of it. It will be seen from the map (fig. 1) that the Mill Close Brook is the boundary of Wensley parish, and to follow the veins northward would be to enter Birchover ground; to facilitate this, a lease of the mineral ground between the river and Mill Close vein was taken, and later, several areas of ground were purchased from the Countess Masereene of Antrim, in this area, to provide room for their overground works and offices. With the idea of unwatering all the Birchover ground, a sough or level was started from the mouth of the Cowley Brook in 1743 and driven west to the Yatestoop vein. This was not completed until many years later.

As Mill Close Mine was opened out it was soon evident that the sough at the intersection with the vein would be fairly shallow, so in order to win a greater depth of vein, a pumping engine was necessary to lift water up to drainage level. A "Fire-Engine" (Newcomen steam engine) was decided on in Aug. 1748 and on 30th Nov. the same year, a 42-in.-cylinder engine was supplied by Darby of Coalbrookdale. The position of the engine in relation to the veins and soughs is seen on fig 1, while fig. 2 shows some detail of the shaft arrangements at the engine. The bill for this engine is of considerable interest.

Coalbrookdale, 2nd, 16th, 30th, 9th mo., 1748.

JOSEPH WHITFIELD.

Bot. of Dale Comp.

For the Governor and Company for Smelting down Lead with Pit and Sea Coal. For Mill Close Mine.

	ct.	qr.	lb.		£	s.	d.
1 Cylinder 42 Diam	54	3	18				
1 Bottom	16	0	0				
1 Sinking Pipe 6 in. Diam. 8 ft. long	6	2	7				
1 Working Barrell 12 Diam. 9 foot	10	1	11				
1 Jackhead Tree bored 9 in. Diam. 6 ft. long	5	2	7				
4 Buckets, 4 Clacks	1	2	27				
1 Works Barrell 9 ft. long 9 in. Diam., Spiggot ends ...	7	1	14				
1 Do.	7	2	24				
	110	0	24	at 30/-	165	6	5

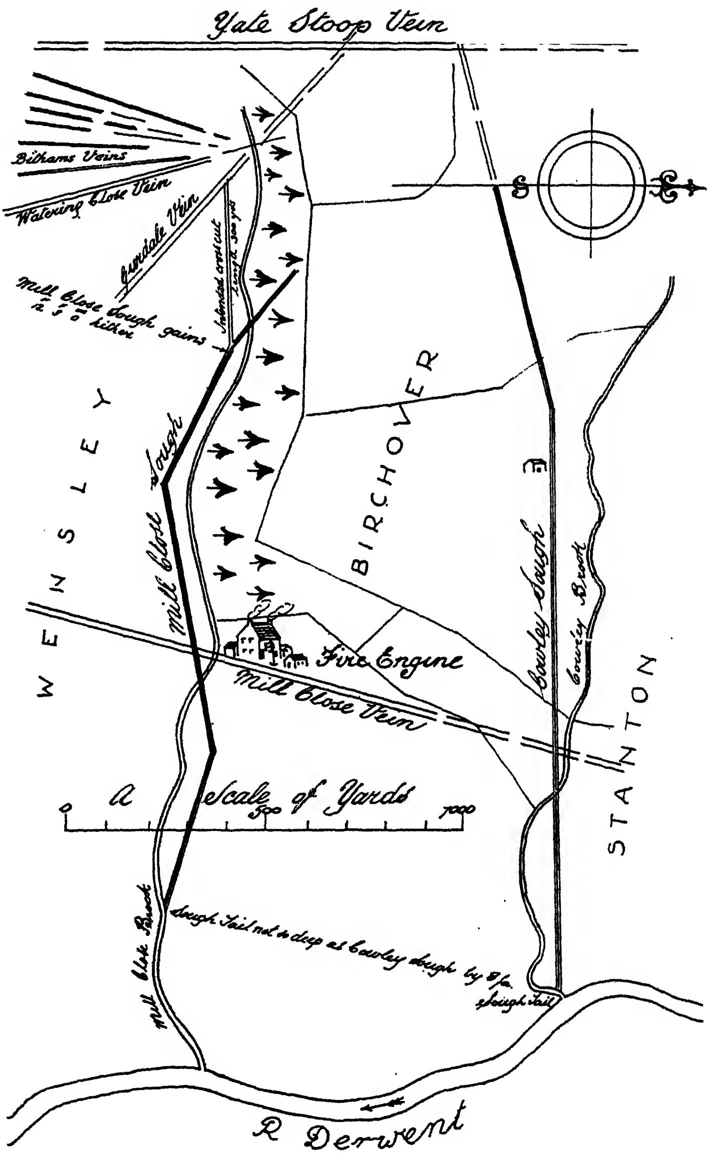

Yate Stoop Vein
Bithams Veins
Watering Close Vein
Gurdale Vein
Intended cross cut Length 300 yds
Mill Close Sough gains
WENSLEY
Mill Close Sough
BIRCHOVER
Fire Engine
Mill Close Vein
Cowley Sough
Cowley Brook
STANTON
A Scale of Yards
0
500
1000
Mill Close Brook
Sough Tail not so deep as Cowley Sough by 8 fa.
Sough Tail
R Derwent

Fig. 1.

1 Clack seat	5	1	19				
1 Pipe 9 ft. 12¾ Diam. spiggot ...	10	2	11				
1 Clack seat	10	2	2				
1 Blast Hole	7	2	14				
1 Bucket Tree 12¾ Diam. 9 ft. long	15	0	6				
	49	0	24	at 18/-	44	5	10¼
1 Door frame	2	1	10				
25 Bars	16	1	14				
6 Sleepers	15	0	13				
2 Braces	1	3	7				
Cast Iron in the Piston	8	1	4				
	44	0	2	at 12/-	26	8	2½
2 Wrot Iron Stems in ye Piston	2	13	4				
1 Wrot Gudgeon turn'd	2	0	25				
	5	0	11	at 6d. lb.	14	5	6
5 Dales				at 1/6		7	6
					250	13	5¾
Allowd on the bars and sleepers 31.1.27 1/6 p ct towds carriage					2	7	3
Remains due					248	6	2¾
Allowd as p bargain					2	2	0
					246	4	2¾

4th 11th mo. called Jany 1748. Recd of Joseph Whitfield Two Hundred Forty Six Pounds Four Shillings In Full Payment for the Within Mentioned Goods Delivered him for the Governor and Compy for Smelting down Lead with Pit & Sea Coal for Mill Close Mine. For Self and Compy. ABRAHAM DARBY.

	Gall		Galls		£	s.	d.
2 Furnaces	25	=	50.0				
1	———		30.0	140 Gall at 8d.	4	13	4
1	———		60.0				

4th 1th mo. Called Jany. 1748 Recd of Joseph Whitfield Four Pound Thirteen Shilling & 4d In Full for Self and Compy.

With due esteem,
Thy Loving Friend,
ABRAHAM DARBY.

Loving Friend,

JOSEPH WHITFIELD,

I had not time this morning to draw out the bill of Parcels before the Waggons were Gone, but I hope thou hast recd. the whole ere this reaches thee Safe and in Good order, & that they please. Upon notice from thee I purpose Meeting thee in Derby; And if Joseph Jones the Engineer Continues

in the mind to have the Crank he was talking of, if he has time I should be pleased to see him along with thee to have his directions about it; please to mention the Inn thou puts up at, and if thou canst, allow me a Day or two to set out in. I am for Self and Compy.

ABRAHAM DARBY.

The tone of this letter emphasises what we know from other sources, that Darby and Whitfield met frequently on various Friends' business, both being active in the work of the Society of Friends.

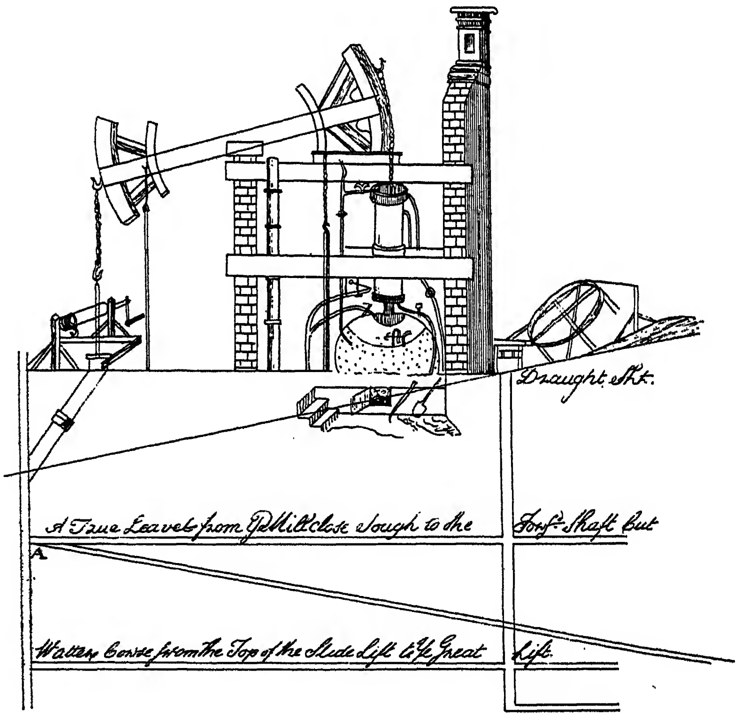


Fig. 2.

On a plan of the mine of 1758 the engine is apparently drawn out in detail, but a critical examination of this drawing (fig. 2) reveals much of interest. First, it is clear that the drawing has been made by a surveyor who was ignorant of mechanics but who desired to embellish his plan (the title, scale, etc., all have florid but crude embellishments as well).

The shape of the boiler, the confusion or lack of valve-gear, though the hanging-rod for the gear is correctly drawn, and the confusion of the pipe connections on the right of the cylinder prove the drawing to be a copy by an uninitiated person. At the shaft on the left, the rod from the small quadrant sinks into the ground, instead of passing down the shaft, while the standing-pipe and jackhead are unconnected. The drawing is, in fact, a very inaccurate copy of the 1717 drawing by Beighton of his engine (reproduced Newcomen Soc. Trans., vol. iv). The chimney ornament, general structure, jack-roller over-shaft, etc., all being well and accurately copied, faults only creep in on the purely engineering details. It will be noted, however, that on the " Draught Shaft " (for drawing the ore) a horse whim is used, and here the draughtsman has had great trouble with his perspective, although it is much simpler than that of the engine.

In 1759 on May 1st, a trial was made of the engine, on a 24-hours' run—4 tons 11 cwts. of coal was used, equivalent of 32 tons 4 cwts. a week, at a cost of 12/- per ton. This test suggested the engine was of approximately 47 horse power. Following the test, on May 15th an agreement was made to sell the engine to Thomas Stephens of Dalefield Mine, the cylinder, cylinder bottom, piston, and snifting-pipe to be delivered at Dalefield Mine for the price of £98 14 6. The prospects of Mill Close changed slightly, and by mutual agreement the sale of the engine was deferred for a while. In Sept. 1764 a general Court minute reads—

> " Mill Close Mine, Derbyshire, has been effectively tried under level and there is no prospect of success.
> *Resolved* to stop the Fire Engine and sell the coal and store such material as will not spoil."

This was carried out and nothing more is heard of the engine. It has not been possible to ascertain whether or not it was finally moved to Dalefield Mine or merely scrapped.

While the engine was at work, the Company had proceeded with Yatestoop Mine and the level was being carried up; in 1757 a partnership was formed of all persons who would derive benefit from this level, and the enterprise con-

tinued as Yatestoop and Cowley Sough Partners. It was completed in 1764 having cost £30,000. In 1766 further mines near the head of Mill Close Level were taken up, making a very compact holding. One of the Company's greatest difficulties was that of transport, and in 1771 the Company, along with other proprietors of the district, had an estimate from Brindley for the cost of making a canal from Chesterfield to Stockwith on the Trent. This line had been surveyed in 1769.

> " The cut is proposed to be 28½ feet wide within the Banks, and each Bank 12 feet.
> The boats to be 70 feet long and 7 wide, to draw 3 feet water. 24 Tuns Burthen—will take 6 Men and 3 Horses every 24 Hours to Navigate each Boat, and it is Supposed each boat will make a Voyage in 4 days.
> At Norwood the canal is proposed to be carried 630 yards under ground."

The total length was 44 miles 6 furlongs. The Company subscribed liberally to this project, as they had previosly shared the cost of the Chesterfield to Ashover Turnpike road of 1766. This improved road and canal would give them much easier transport of their smelted lead to the Hull market. At the same time (1771) an estimate was made of the cost of unwatering Mill Close Mine, preparatory to re-opening it, but it was thought to be too high.

The general policy of the Company about this time was turning towards consolidation of all its works in the north Pennines. The Alston Moor area, particularly Nent Head and Garrigill was flourishing, and large leases were being developed in Teesdale. There was discussion of the advisability of continuing the Welsh Mines and no further leases were taken or renewed in any area except Cumberland and Durham. In 1775 the Derbyshire accounts showed a considerable loss on the year's working, and in 1776 a special Court was called to consider extensive reports on all the Derbyshire undertakings. A half-share in the Yatestoop and Cowley Sough was sold for £2,640 to the other partners, and all mines in Derbyshire except Mill Close, Watering Close,

and Ballington Wood were sold. These were kept on in a very quiet way, several " takes " and the smelt mill being sublet. The agent, Joseph Whitfield, retired from the Company and returned to his home at Burnlaw, Allendale. No further minutes relating to Derbyshire occur until a formal note in 1792 of the final surrender of all leases. It seems fairly certain from other sources that all activity ceased in 1778.

Mill Close Mine remained derelict after the L.L.Co. left it, until 1859, when it was re-opened by Mr. E. M. Wass, and began its career as one of the greatest mines in Britain.

A ROMAN CUP OF TIN, FROM HIGH ROCHESTER, NORTHUMBERLAND.

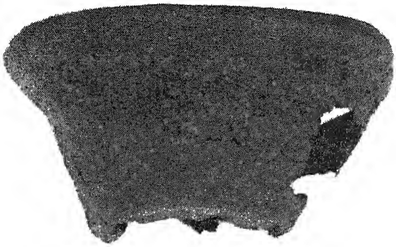
By

I. A. RICHMOND, M.A., F.S.A., AND J. A. SMYTHE, PH. D., D.Sc.

The little cup here described is one and a half inches high. It has a flat bottom, with foot-stand formed by a slight thickening of the wall. The base is one and three-quarter inches in diameter; above which the straight sides slope outwards and are finished with a slightly everted lip, thickened in the same way as the footstand. At the top, the original diameter of the cup was about three and five-eighths inches, but the shape has been distorted by squeezing (Fig 1).

The little vessel came into the possession of the Society of Antiquaries of Newcastle-upon-Tyne in 1925, with the collection formed by the Rev. T. Stephens, sometime vicar of Horsley-on-Rede. The Roman objects in this collection came chiefly from the adjacent fort of High Rochester; but sometimes from further afield, as, for example, the bronze saucepan from the Wanny Crags, with which the earliest account[1] of this cup was associated. There has, in fact, been some ambiguity as to where the cup was actually found, and the evidence is worth collection here.

The vessel was first mentioned, and drawn, in 1885. Mr. Stephens writing from Horsley, then stated[2] that " a small leaden vessel somewhat in the form of the ordinary *acetabulum* was found near here a short while ago. It bears the name TACITI rudely scratched on the bottom." This note was drawn upon by Thompson Watkin, who refers[3] to the cup in his account of Roman inscriptions for that year, in the following terms: " At Horsley-on-Rede, near the Risingham station, there has recently been found a small Roman vessel of lead, on the bottom of which was " scratched " the word



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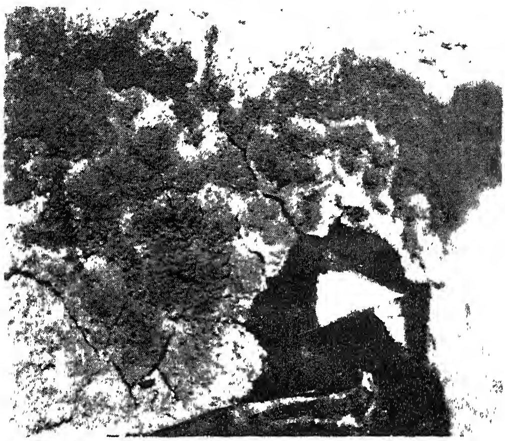

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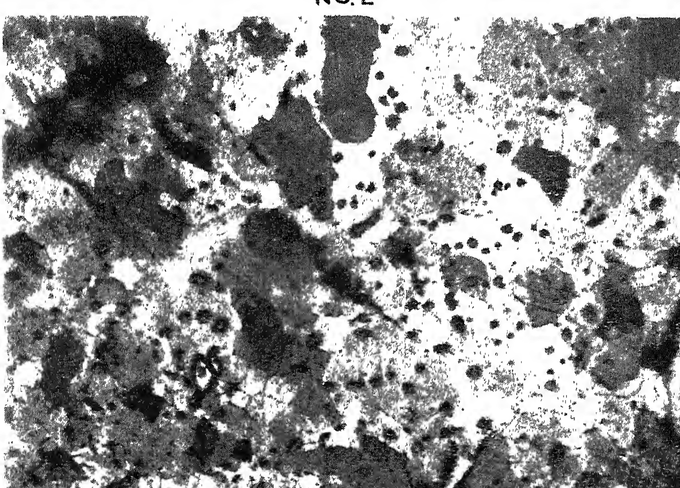


NO. 3

TACITI." Thence the reference was transferred by Hübner to *Ephemeris Epigraphica*, where the cup is not unnaturally listed[4] under Risingham.

In 1888, the cup was exhibited by Mr. Stephens himself, who reported[5] that it came from *Bremenium*. If this were an isolated statement by Mr. Stephens, we might have wondered whether it was a mistake. But its validity is confirmed[6] by a later conversation between Mr. Stephens and Miss Mothersole; when the vicar "spoke with great regret of a beautiful little lead *acetabulum* with a name on the bottom, which had come from *Bremenium*. He showed it to a visitor staying at the Redesdale Arms, who did not realize its fragile condition and crumpled it to bits in his hands!" In the face of this evidence, there can be little doubt as to the provenience of the cup. It came from High Rochester, and its assignment to Risingham is due to an unfamiliarity with local topography shared by Watkin and Hübner.

Despite the disaster recorded by Miss Mothersole, large parts of the cup survived, though between 1925 and 1936 deterioration visibly continued as it reposed in the Museum of the Society. At the base of the object an increasing litter of powder and fragments marked the progress of disintegration. No close examination of the vessel took place, however, until the writer had occasion to study it for the account of Roman Redesdale, presently to be published in the Northumberland County History.

It is shown in this paper that the cup is made of an alloy of lead and tin, very rich in the latter metal. Its disintegration is due to a disease inherent in the nature of the metal, a molecular change which disrupts tin at low temperatures. This explains why Roman objects of pure tin are of the highest rarity, and it is a property of tin which did not escape notice in the ancient world, though it was imperfectly understood. Aristotle clearly describes it, as Krause[7] has pointed out, noting that "Celtic tin is said to disintegrate much quicker than lead. . . . It even disintegrates in cold, when it is freezing, since, as they say, heat is contained within it and is being compressed owing to the weakness (of the metal)." The same observation is made by Plutarch, though

he fails to distinguish between tin and lead and obscures the details of his theory by an awkward comparison with the bodily functions. No other or more accurate description of the phenomenon was, however, written until modern times.

I.A.R.

On close examination, the metal was found to be singularly free from corrosion; it was traversed by numerous cracks and was so brittle that it could hardly be handled without breaking into angular fragments, which showed a bright metallic fracture. On the inside surface there were circular, wart-like excrescences, which appeared to have started at the bottom and spread upwards almost to the rim. When fragments of the cup were gently heated in a sloping tube they melted, and the liquated metal, on solidifying, was soft and malleable and like tin in appearance. Analysis of this liquated metal showed it to be a tin-lead alloy, rich in tin:

Tin	95.64
Lead	4.49
	100.13

These observations suggested strongly that the metal had succumbed to the tin-disease and experiments to test the point have made this abundantly clear. Before these are detailed, however, a brief account of the development of our knowledge of this subject will be given.

Apart from references in the classical authors, which have been dealt with already, the first mention of the phenomenon appears to have been made by Erdmann[8] in the year 1851. Since then, it has engaged the attention of numerous chemists. Most of the earlier observations were concerned with the crumbling of tin organ-pipes during severe frosts, and von Fritzche[9] reports the destruction of a consignment of soldiers' buttons, made of tin, at St. Petersburg, during the winter 1867/68. Schaum[10] describes the onset of the trouble in these

words: " Das Zinn bekommt zunächst an einzelen Stellen eine stengelige oder blätterige Struktur, während gleichzeitig ein graues Pulver sich absondert." This description accords well with the case at present under discussion.

In the same year, Prof. Ernest Cohen of Amsterdam began his study of the subject. To him and his collaborators we owe most of our knowledge of it and numerous papers from his pen have appeared at intervals from this time up to the present day.[11]

Briefly stated, the cause of the tin-disease (*Zinnpest, Museumkrankheit)* resides in this. There are two forms of tin, the ordinary or white tin, S.G. 7.285, and grey tin, S.G. 5.765. The relation between these is characterised by a definite temperature of transformation or transition which, according to Cohen's latest determinations, is 13°.2 C (56° F) and is such that the white form is stable above this temperature and the grey below it. The change (enantiotropic) is sluggish and, within a limited range of the temperature of transition, may be almost indefinitely delayed, if only one of the forms is present. Thus, most of the ordinary tin in temperate climates, during winter-time, is unstable (or meta-stable); it tends to persist unless the change is favoured either by great reduction of temperature, or by the presence of particles of the stable form. If the grey variety be heated well above the temperature of transition, say, to 100° C, it passes quickly into the white tin stable at that temperature.

It may be noted that the densities of the two varieties differ considerably and, from the values given above, it can be calculated that in the transformation from white to grey tin the volume increases by nearly 26 per cent. Thus the progress of the change radially from an infected spot results in the production of the warty excrescences or blisters which are so characteristic a feature of the phenomenon. They may be seen in the photograph of the cup (Fig. 2) and compared with similar photographs published by Cohen (*Chemistry and Industry, op. cit.*).

Confirmatory evidence of the disease in the present case may be sought in two ways: either by inoculation of a sheet of white tin by contact with particles of the grey tin from

the cup, at a temperature suitably below that of transition; or by converting the grey tin into white tin by heating it, recording at the same time the change in density which the metal undergoes in the process. For various reasons which need not be discussed here, the first method is not very easy to carry out. The second method suffers from the disadvantage that such material as the cup afforded was a mixture of the two forms. However, the evidence obtained from it is quite satisfactory and the method adopted will now be briefly described.

Some fragments of the cup were gently crushed, without grinding, in a mortar and the coarse material further comminuted by rubbing between thumb and forefinger and passed through a 40-mesh sieve. The treatment was repeated with the oversize material until it ceased to be effective. The coarse particles were malleable and consisted, for the greater part, of white tin. The fine powder also contained malleable particles and was evidently a mixture of the two varieties. It was thoroughly levigated with water to remove lighter particles of grit and scale, then washed with alcohol and dried. Under the microscope it appeared fairly free, but not quite free, from non-metallic material (scale, grit, etc.).

The specific gravity was found to be 6.30. The specific gravity bottle in which the determination was made with its contents of metal-powder and water was now heated for half an hour at 100° C, then cooled to atmospheric temperature and the specific gravity of the powder again determined. It was now 7.18.

Knowing the composition of the alloy and the densities of lead and of the two forms of tin, and assuming that the volume-change on alloying the two metals is negligible, then the calculated density of the alloy when the tin is all white is 7.41, and when it is all grey, 5.90. These values approximate fairly closely to those given above, viz. 7.18 and 6.30. The difference in the case of the heated alloy is to be ascribed partly to the presence of lighter extraneous matter not removed by levigation. The much greater difference in the other case naturally arises to some extent from the same cause, but is chiefly to be referred to the presence of the heavier white tin

in the powder. Neglecting the first factor as relatively small and indeterminate, then it can easily be calculated that the powder derived from the cup consisted of: white tin, 30.1; grey tin, 65.4; lead, 4.5 per cent. the S.G. of this alloy being 6.30.

It is of interest to recall that a Roman bowl of similar composition to the Rochester Cup was discovered some years ago at Appenshaw and investigated by Gowland,[12] who found it to contain: tin, 94.35; lead, 5.06 per cent. Gowland was impressed by the brittleness of the alloy and the absence of evidence of chemical alteration. He writes: "The metal is not much oxidised, yet it is so excessively brittle that it can be easily broken with the fingers. The effect of time upon it has resulted in a complete alteration of its molecular structure. . . . On melting and casting a small fragment, I found that the crystalline structure disappeared and the metal regained its original toughness." This metal was examined shortly afterwards by Cohen,[13] who showed, by the decrease of volume on heating, that it consisted partly of grey tin and had thus suffered from the tin-disease.

In several of the cases of the disease recorded by Erdmann and by Schaum (*op. cit.*) the object affected has been an alloy of tin containing about 5 per cent. of lead. It is possible that this amount of lead confers limited stability on the tin; it is certain that larger amounts inhibit the enantiotropic change and that pure tin is so unstable that it cannot survive many centuries of burial. This state of affairs corresponds closely both with the frequency of occurrence and state of preservation of ancient objects of tin and tin-lead alloys. Some recent investigations[14] have shown that the rate of change of white to grey tin varies in different grades of virgin tin and to still greater extent owing to the presence of added alloying elements, 0.1 per cent. of bismuth, for example, reducing the rate of change of pure tin to a hundredth of its value and 0.5 per cent. suppressing the change completely.

One more point remains to be considered and that concerns the method of fabrication of the cup. Metallographic examination shows the metal to have a granular structure (Fig. 3), but this is not necessarily proof, in the case of a metal like tin, that

the object has been cast, since the metal anneals itself at the ordinary temperatures. The leady inclusions, however, best seen on a polished but unetched surface, give a clue to the history of the alloy, particularly when compared with those in a Roman alloy of the same composition from Corbridge; for whereas in the Corbridge alloy these inclusions are definitely oriented so as to suggest immediately a casting structure, in the Rochester cup they are uniformly dispersed and convey no such implication. The inference to be drawn is that the orientation of the inclusions in the original casting from which the cup was made has been destroyed by working the metal, or, in other words, that the cup has been wrought, not cast.

J.A.S.

EXPLANATION OF THE PLATE.

Fig. 1. Side view of cup, half natural size.

Fig. 2. Inside of the cup showing cracks and the warty excrescences of the tin-disease (X 2). The black patch at the bottom is a hole.

Fig. 3. Micrograph of the metal of the cup, etched with alcoholic hydrochloric acid, showing the background of crystallised tin. The small, unoriented black spots are the lead (X 100).

REFERENCES.

[1] *PSAN*[2], ii, 64: p. 153 for a tail-piece illustrating the cup and thus establishing identity.

[2] *ibid.*, 64.

[3] *Arch. Journ.* xliii, 280.

[4] *EE.* vii, 1151.

[5] *PSAN*[2] iii, 321.

[6] *Agricola's road into Scotland*, 177.

[7] E. Krause, *Prometheus*, 1900, 44, p. 701, cf. E. Cohen, *Zeitschrift für physikalische Chemie*, 1901, xxxvi, 513, quotes Aristotle, *de mirabilibus auscultationibus*, 51 ; τὸν κασσίτερον τὸν Κελτικὸν τήκεσθαι φάσι πολὺ τάχιον μολύβδου· Σημέιον δὲ τῆς ἐυτηξίας ὅτι τήκεσθαι δοκεῖ καὶ ἐν τῷ ὕδατι ☉ Χρώζει γὁυν , ὡς ἔοικε, ταχύ· τήκεται δε καὶ ἐν τοῖς ψύχεσιν , ὅταν γένηται πάγη , ʼεγκατακλειομένου ʼεντός , ὥς φασι , καὶ συνωθουμένου τοῦ θερμοῦ τοῦ ʼενυπάρχοντος ʼαυτῷ , διὰ την ἀσθένειαν ; also Plutarch, *Quaest, conviv.*, λ , 7-8 ; ʼεν μὲν γὰρ τοῖς μέγαλοις χειμῶσιν ʼακόναι μολίβδου διατηκόμεναι τό τε τῆς ʼαφιδρώσεως και τὸ πολλοῖς μὴ πεινῶσιν συμπίπτειν τὴν βουλιμιάσιν , κατηγορεῖ μᾶλλον ʼαράιωσιν καὶ ῥύσιν ἢ πύκνωσιν τοῦ σώματος · Αραιοῦνται δὲ χειμῶνος μὲν ὥσπερ ἔιρηται τῇ λεπτότητι , ἄλλως δὲ τόν κόπον καὶ τῆς κινήσεως ʼαποζυνόυσης τὴν ʼεν τῷ σώματι θερμότητα · λεπτὴ γὰρ γενομένη καὶ κοπιῶσα ῥεῖ πολλὴ και διασπέιρεται διὰ τοῦ σώματος·

[8] O. L. Erdmann. *Journ. f. prakt. Chemie.*, 1851, **52**, 428.

[9] *Berichte*, 1869, **2**, 112, 540.

[10] K. Schaum. *Ann. der Chemie* 1899, **308**, 18.

[11] *Z. physikal Chemie* 1899 **30**, 601.
1900 **33**, 57; **35**, 588.
1901 **36**, 513.
1904 **48**, 243; **50**, 225.
1908 **63**, 625.
1927 **127**, 178.
1935 **173**, 1, 32.

Also, *Chemistry and Industry* 1929, **48**, 162.
For an excellent general account of the subject, see van t' Hoff's *Zinn, Gyps und Stahl* 1901 (Vortrag gehalten im Verein der Deutschen Ingenieure zu Berlin.)

[12] W. Gowland, *Arch.* 1898, **56**, 13.

[13] E. Cohen, *Z. physikal. Chem.* 1900, **33**, 57.

[14] G. Tammann, K. L. Dreyer, *Z. anorg. allg. Chemie.* 1931, **199**, 97.

THE FLORA OF THE ISLANDS OF MINGULAY AND BERNERAY.[1]

by

W. A. Clark, B.Sc., Ph.D.

During the past four years certain members of the staff of the Department of Botany, King's College (University of Durham), have carried out an investigation of the Flora of Raasay and the neighbouring islands, the results of which have already been published.[2] This summer the investigation was extended to include the islands of Soay, Canna, Rhum, and Eigg. In addition, two of us, Dr. G. Heslop Harrison and myself, spent a period of 7 days on Mingulay and Berneray, the two southernmost islands of the group known as the Barra Isles, and this paper embodies the botanical findings of that visit. The main object of our investigation was to extend our knowledge of the Flora and Fauna of the Hebrides,[3] but it was also hoped that some light might be shed on the larger problem of plant distribution in the Hebrides, certain aspects of which have already been discussed by Professor J. W. Heslop Harrison in a previous paper.[4]

The island of Mingulay lies 12 miles south of Castlebay, Barra, and is separated from Berneray in the south by the Sound of Berneray which reaches a breadth of ¾ of a mile, and from Pabbay in the north by the Sound of Mingulay 2 miles wide. Both Mingulay and Berneray are used for sheep

[1] The researches described in this paper were rendered possible by a grant from the Research Committee of King's College (University of Durham), and to them I tender my very best thanks.

[2] "The Natural History of the Isle of Raasay and of the Adjacent Islands of South Rona, Scalpay, Fladday, and Longay," Proc. Durham Univ. Phil. Soc., vol. x, pt. v, pp. 246-351.

[3] The Department of Botany, King's College, University of Durham, has in preparation a comprehensive Flora of such islands of the Inner and Outer Hebrides as are included in Vice-counties 103, 104 and 110; this work was commenced in 1934.

[4] "The Flora of the Inner Hebridean Islands, Raasay, South Rona, Scalpay, Fladday, and Longay," B. E. C. 1936 Rep., pp. 299-303.

grazing. The former is inhabited by a keeper and two shepherds though formerly it supported a population of 140, and on the latter is Barra Head Lighthouse Station to which four families are attached.

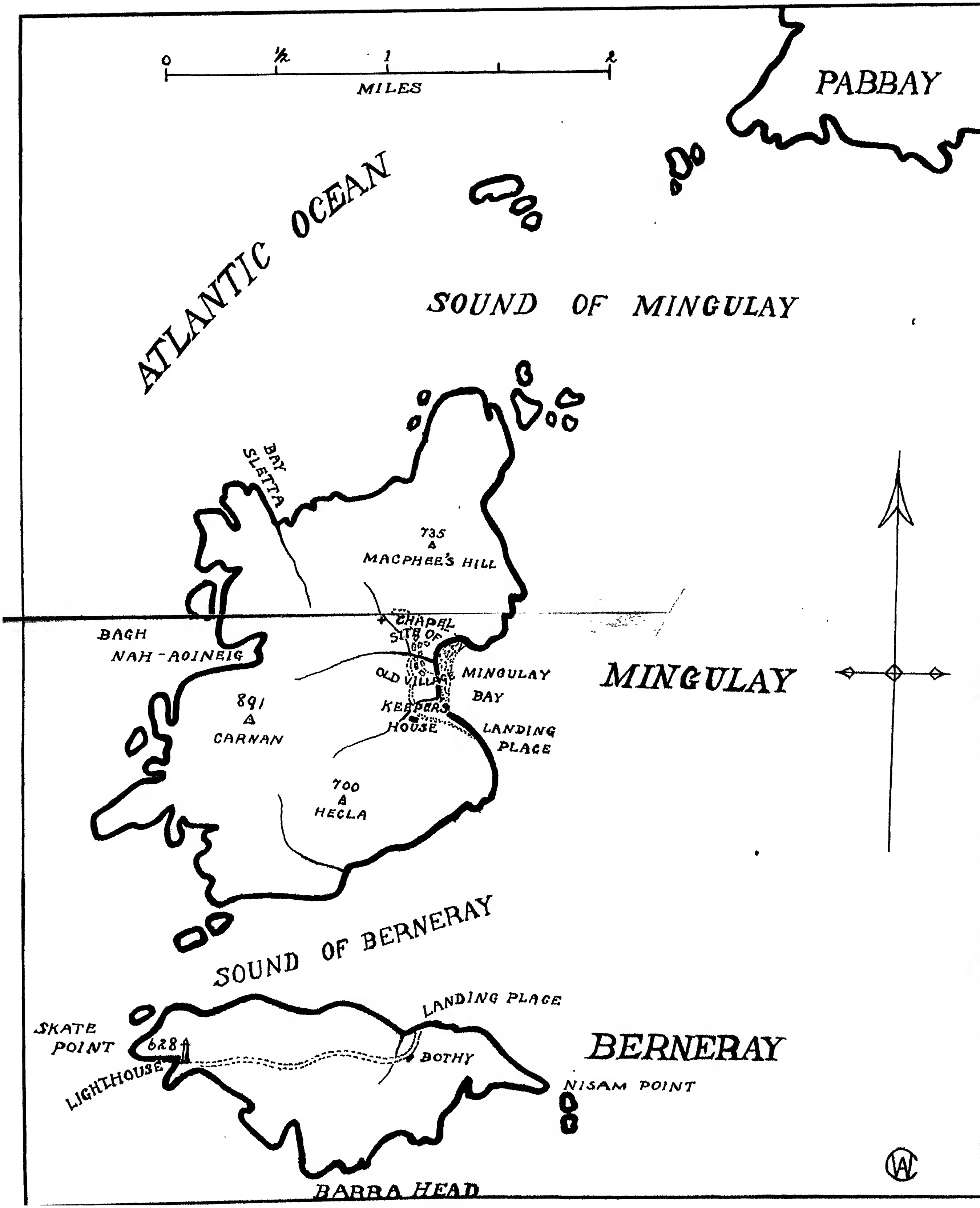
Transport to the islands is either by means of the lighthouse supply boat which sails, once weekly during the summer and once fortnightly during the winter, from Castlebay to Berneray calling at Mingulay en route, or by a lobster boat which makes the journey to the lobster grounds off Berneray two or three times a week during the summer. As the duration of our stay was limited to 7 days, and we wanted to visit both islands, we had to go by the lobster boat which landed us first of all on Mingulay, returning four days later to take us to Berneray. After leaving Castlebay one passes in turn the islands of Vatersay, Sandray, and Pabbay, of which the first only is inhabited. They are separated from one another by deep sounds, through which the Atlantic sweeps forming very dangerous tidal races.

Mingulay is the larger of the two islands being approximately 3 miles long and 1½ miles broad, and it extends in a north and south direction. In the north and west the island is bounded by a series of cliffs and stacks; the most noteworthy of these is the cliff of Aoineig in the west which rises perpendicularly from the sea to a height of 753 feet. Broken up by gullies, inlets and caves, they provide some of the most magnificent sea cliff scenery to be found in Britain, and at the same time a nesting place for thousands of sea birds. Mingulay Bay, the site of the old village, is situated midway along the east side of the island, and has a maximum breadth of ½ a mile. The north half of the bay consists of a storm beach which stretches inland for a distance of ¼ of a mile. On the dunes at the head of this beach, the Sea Holly grows abundantly. The margin of the southern half of the bay consists of sandy cliffs, 20-30 feet high, fringed on the seaward side by a narrow sandy beach, while in the extreme south it consists entirely of rocky cliffs. The landing place is situated here, and from it a rough path leads first of all to the keeper's house, and then to the old village—a total distance of ½ a mile. The islanders, preferring Vatersay to Mingulay, deserted the

village some 20 years ago, and it now consists of approximately 28 ruined houses scattered irregularly round the head of the storm beach which is gradually encroaching on it. Quite close to the village, but on the seaward side, is the old burial ground, a circular mound surrounded by a dry stone dyke. On it wooden crosses and stones still stand bearing silent witness to the islanders who once eked out a precarious existence there. Behind the village and on higher ground stands the chapel which is still in an excellent state of preservation. The upper story, consisting of one large room, was obviously the place in which the islanders worshipped, the lower story serving as a dwelling place. The keeper kindly allowed us the use of one of the rooms for a laboratory, and a flat sandy piece of ground nearby provided a good site for our camp. We had, of course, to bring all our provisions with us from Castlebay, and we carried them over from the landing place to our camp in sacks.

Opening into the bay is a large valley which runs right across the island in an east and west direction, and it appears from the sea almost to divide the island into two. It is limited in the west by the cliffs of Aoineig, and from the cliff the land gradually slopes down to Mingulay Bay. Carnan (891 feet), the highest point on the island, is situated in the west of the southern half of the island, and a ridge connects it with Hecla (700 feet) in the south. The northern half is dominated by Macphee's Hill which attains a height of 735 feet. The valley is drained by two streamlets which enter the sea separately, one near the old village and the other further south, close to the keeper's house. Sheltered from all directions with the exception of the east, and possessing in its lower reaches fairly flat areas of good land, it is not surprising that the valley was chosen as the site for the village. The old fields stretch for a considerable way up the valley, and had apparently been used mainly for grazing. Nearer the village some of them had been cultivated, and now support a rich colony of weeds of cultivation, of which *Potentilla Anserina* is the most prominent, forming in some of the fields an almost pure association. The soil is of a sandy nature, and Jehu and Craig[5]

[5] "Geology of the Outer Hebrides. Part I—The Barra Isles." Trans. Roy. Soc. Edin., vol 53, pt. 2, pp. 419-442.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1
2
MILES
PABBAY
ATLANTIC OCEAN
SOUND OF MINGULAY
BAY SLETTA
735
MACPHEE'S HILL
SITE OF CHAPEL
BAGH NAH-AOINEIG
OLD VILLAGE
MINGULAY BAY
MINGULAY
891
CARNAN
KEEPERS HOUSE
LANDING PLACE
700
HECLA
SOUND OF BERNERAY
LANDING PLACE
SKATE POINT
628
BOTHY
BERNERAY
LIGHTHOUSE
NISAM POINT
BARRA HEAD

report that it is said by fishermen to have grown the best potatoes in the Long Island. The southern part of Mingulay slopes towards the Sound of Berneray, and is drained by a small stream. Here, again, on the flatter regions we found traces of old fields and some ruined houses.

Berneray, stretching more or less in an east and west direction, is 2 miles long and ¾ of a mile broad. In the west and south-west, like Mingulay, it is bounded by a wall of rock which, at its westernmost extremity, reaches a height of 628 feet. On this prominence, known as Skate Point, Barra-head Lighthouse Station is situated, the second highest light-house in the world. Towards the north, the island gradually slopes down to the Sound of Berneray. A pier has been built here and a road constructed, up which supplies of paraffin, etc., are conveyed by motor lorry to the lighthouse. The lighthouse keepers and their families are the only inhabitants of the island, though traces of former inhabitants were found in the form of some ruined houses and patches of cultivated ground, now also over-run with Silver Weed. While on Berneray we stayed in a bothy kindly lent to us by Mr. MacLachlan—the head lighthouse keeper.

From the geological standpoint the islands are uninteresting, consisting almost entirely of gneisses. The climate is on the whole mild, as one would expect from the position of the islands, but they are continually subjected to the full force of the prevailing westerly winds, and this latter fact is partly reflected in the extreme dwarfness and stunted appearance of the vegetation generally. The average rainfall for the past three years, as recorded by the lighthouse keepers, is only 38 inches, but it is probably greater than this figure as no allowance is made for evaporation which must be considerable during the gales which usually accompany the rain.

The greater part of both islands consists of bare moorland interrupted frequently by outcrops of gneiss. The dominant plant of these areas is *Molinia cærulea* with *Carex echinata* sub-dominant. The islands are treeless if one excludes some very dwarf specimens of *Populus tremula* straggling up the sandy cliffs in the south of Mingulay Bay, and they are like-wise devoid of lochs though a number of small rocky and peaty

pools were observed in the north of Mingulay. Saltmarshes, too, are lacking, but in spite of this *Glaux maritima* occurs abundantly on the top of the cliffs in the west of Mingulay, a fact which indicates the height to which the spray is hurled during the fierce Atlantic storms. Taking cognisance of all these facts, it is not surprising that the total list of plants amounted to only 206 species.

Perhaps the two most interesting features of the vegetation of the islands were the peculiar local distribution of certain species and the scarcity and absence of species one normally associates with the Hebrides such as the Common Heather, the Blaeberry, the Crowberry and the Sweet Gale, only to mention a few. The former feature is due to the very exposed nature of the islands, many species being unable to grow except in sheltered hollows or on southern exposures. Why *Calluna vulgaris* should be so rare and such species as *Vaccinium Myrtillus*, *Empetrum nigrum* and *Myrica Gale* completely absent is a much more difficult matter to explain, and further research in the area is necessary before it can be elucidated. In contrast to the rareness and absence of the abovementioned species, is the abundance of such species as *Hydrocotyle vulgaris*, *Anagallis tenella*, and *Scilla verna* which occur commonly all over both the islands.

Of the total number of plants recorded 83 were restricted to Mingulay and 9 to Berneray. In seeking to explain this preponderance of species limited in distribution to Mingulay, the fact that it is the larger of the two islands, and that a longer time was spent on it must be taken into account. The real key to the problem lies, however, not so much in its larger size, but in the fact that it possesses an extremely sheltered valley which together with the dunes and cultivated areas at its mouth, provide the necessary habitats for almost all the species in question. Thus all but 17 of the 83 are located in or near the valley which itself might be said to account for 27 of that number. The dunes account for a further 10 and the remaining 29 are weeds of cultivation. It is difficult to understand why none of the latter occur in the old cultivated areas on Berneray, but no doubt the more extensive cultivation of Mingulay and the extremely sheltered position of the fields are partly responsible.

An interesting association of plants was found on the sandy cliffs fringing the south part of Mingulay Bay. It included *Populus tremula*, *Hedera Helix*, *Rosa glaucophylla*, *Ranunculus Ficaria*, *Brachypodium sylvaticum* and *Equisetum sylvaticum*, and with the exception of *R. Ficaria* this was the only locality in which these plants were found. It is suggested that they represent all that is left of a former woodland association.

Two members of the cliff flora are worthy of mention viz. *Silene acaulis* and *Oxyria digyna*. The former was mainly confined to the cliffs in the north-west of Berneray, only two clumps being observed on the north side of Hecla, Mingulay; the latter was restricted to the cliffs north of Bay Sletta, Mingulay. They are particularly interesting because both form part of the cliff flora of the east side of Raasay, and are therefore brought into line with the conditions pertaining there. It does seem probable, as Professor J. W. Heslop Harrison has suggested, that such plants are pre-glacial survivals, the ledges on which they occur having behaved as "nunataks."

In conclusion the writer wishes to thank Professor J. W. Heslop Harrison for having suggested the investigation in the first place and for his help and advice during its course. I am also very grateful to Miss H. Heslop Harrison, M.Sc., for her help in identifying the grasses and to Messrs. Chapple and Pugsley, and Dr. Butcher for help with critical genera.

Thalictrum arenarium Butcher.
Common on the dunes and sandy cliffs, Mingulay Bay.

Ranunculus Flammula L.
Of general occurrence in wet places, both islands.

R. acris L.
On both islands but confined to the cliffs on Mingulay.

R. repens L.
Uncommon, as a weed of cultivation both islands.

R. bulbosus L.
Only on the dunes and sandy places, Mingulay Bay.

R. Ficaria L.
Quite rare and local, both islands. On Mingulay, only a few plants were observed on a rocky ledge of the cliffs in the south of Mingulay Bay.

Caltha palustris L.
Sparingly in wet places, old fields, Mingulay only.

Fumaria officinalis L.
A weed of cultivation in the keeper's garden.

Cardamine hirsuta L.
Limited to the streamlet and adjacent marsh near the landing place, Berneray.

C. pratensis L.
Very rare; a few plants were observed in the marsh beside the keeper's house, Mingulay.

Cochlearia officinalis L.
Sparingly distributed on the shores and cliffs, both islands.

C. groenlandica L.
Only observed on the cliffs, Skate Point, Berneray.

Brassica arvensis L.
On the previously cultivated areas, Mingulay only.

Capsella Bursa—pastoris Medic.
On waste ground, both islands.

Viola palustris L.
Common enough in wet places and Sphagnum bogs, Mingulay; apparently not recorded from Berneray.

V. Riviniana Rchb.
Not common; on sheltered banksides, Mingulay only.

Polygala vulgaris L.
Common on the moors of both islands.

P. dubia Bellynck.
Fairly common on sandy cliffs, both islands.

P. serpyllifolia Hose.
Only recorded from Mingulay, rare.

Silene maritima With.
Limited to, and common on, the cliffs in the north and west of both islands.

S. acaulis L.
Not uncommon on the cliffs north of Skate Point, Berneray, but very rare on Mingulay where it is limited to two or three clumps on the north slope of Hecla.

Lychnis Flos-cuculi L.
Fairly common, marshy places, both islands.

Cerastium vulgatum L.
Common near the old habitations and on the cliffs, both islands.

Stellaria media Vill.
In the old fields, both islands.

S. neglecta Weihe.
Abundant in the gullies of the western cliffs, both islands.

S. uliginosa Murr.
One of the species found only on Berneray where it was observed in the marsh beside the landing place.

Arenaria serpyllifolia L.
Rare on dry sandy banks near the old houses, Mingulay Bay.

A. peploides L.
On the storm beach, Mingulay Bay only.

Sagina procumbens L.
On the cliffs and bare rocky places on the moors, both islands.

S. subulata. Presl.
Much rarer than the latter, on the cliffs in the west of Mingulay.

Spergula sativa Boenn.
As a weed of cultivation in the keeper's garden.

Montia fontana L.
Very common in the wet gullies of the cliffs in the west and north of both islands.

Hypericum pulchrum L.
Common on banksides, sides of streamlets, and sheltered places of both islands.

Linum catharticum L.
Common enough on the sandy cliffs in the west of both islands.

Geranium molle L.
One colony only, consisting of very dwarf plants, in a sandy field near the chapel, Mingulay.

Erodium cicutarium L'Herit.
Found only on the dunes, Mingulay Bay.

Trifolium pratense L.
Quite common on grassy banks and old pastures.

T. repens L.
Thinly spread in old pastures, both islands.

Anthyllis Vulneraria L.
Rare and local on cliffs and sandy places in the east of both islands.

Lotus corniculatus L.
Not uncommon on the dunes and cliffs in the east of both islands.

Vicia Cracca L.
Uncommon and confined to areas previously cultivated and the dunes, both islands.

V. sepium L.
One plant only, in old field, Mingulay Bay.

Lathyrus pratensis L.
Sparingly distributed on sandy cliffs and banks of streamlets, both islands.

Spiræa Ulmaria L.
Common in marshy places, both islands.

Potentilla erecta Hampe.
Universally distributed on both the islands.

P. Anserina L.
Abundant in the old fields and in waste places around the old habitations, both islands.

Rosa glaucophylla Winch. (agg.)
(a) Var. **typica**. Two or three plants on sandy cliffs in the south of Mingulay Bay.
(b) Var. **Reuteri** God. One plant growing beside the preceding.

R. Sherardi Dav. (agg.)
(a) Var. **typica** W.D.
(i) f. **pseudomollis** Ley. Not found on Mingulay or Berneray but collected on Barra.

Sedum roseum Scop.
Abundant on the cliffs of both islands.

S. anglicum Huds.
Common on the rocks near the sea and on the outcrops of gneiss in the moors.

Drosera rotundifolia L.
Common but local in boggy " slacks " in sheltered places, both islands.

Callitriche stagnalis Scop.
In peaty pools and streamlets, both islands.

Epilobium palustre L.
Common and generally distributed, both islands.

Hydrocotyle vulgaris L.
Common and widespread all over both the islands.

Eryngium maritimum L.
Occurs abundantly on the upper part of the storm beach quite close to the old village, Mingulay Bay.

Anthriscus sylvestris Hoffm.
Only the leaves of one plant were observed in a sandy field, Mingulay Bay.

Ligusticum scoticum L.
Sparingly on the cliffs of both the islands; the plants were very dwarf.

Angelica sylvestris L.
Everywhere abundant, particularly on the cliffs, both islands.

Heracleum Sphondylium L.
Rare on the dunes and sandy cliffs, both islands.

Daucus carota L.
Chiefly on the sandy cliffs in the east of both islands.

Hedera Helix L.
Only observed straggling up the sandy cliffs in the south of Mingulay Bay alongside *Populus tremula* and the roses.

Lonicera Periclymenum L.
Apparently only recorded from Mingulay where it is rare and confined to sheltered banksides.

Galium verum L.
Another of the plants restricted to the dunes, Mingulay Bay.

G. saxatile L.
Not common; only observed on the north side of Hecla above 400 feet along with *Juncus squarrosus,* also not found elsewhere.

G. Aparine L.
Only one plant observed in one of the old fields, Mingulay Bay.

Scabiosa Succisa L.
Common all over both islands.

Solidago Virgaurea L.
Fairly common on sheltered banks, Mingulay, but not recorded from Berneray.

Bellis perennis L.
Common in previously cultivated areas.

Antennaria dioica Gærtn.
Unexpectedly rare and local, being confined to sheltered places in the east of both islands.

Achillea Millefolium L.
Common enough in sandy places, both islands.

Matricaria inodora L.
Found only as a weed of cultivation in the keeper's garden; form **maritima** with very succulent leaves is one of the dominant plants of the rocky ledges and gullies of the sea cliffs in the west and north of both islands.

Matricaria suaveolens Buchenau.
Again one of the weeds in the waste ground beside the keeper's house.

Artemisia vulgaris L.
Also occurs on the waste ground.

Tussilago Farfara L.
On the sandy banks of the streamlets running into Mingulay Bay.

Senecio vulgaris L.
Also as a weed in the keeper's garden.

S. Jacobæa L.
Restricted to the sandy cliffs, Mingulay Bay.

S. aquaticus Hill.
Much more common than the latter; in marshy places, both islands.

Arctium sp.
One plant, too young to identify, was observed in the keeper's garden.

Cnicus lanceolatus Willd.
On the dunes, Mingulay Bay, and on a sandy cliff, Berneray.

C. arvensis Hoffm.
Abundant in the old fields, both islands.

Centaurea nigra L.
Not uncommon, old fields, banksides and sandy cliffs, both islands.

Hieracium Pilosella L.
Limited to one station on the east side of each of the islands, and curiously enough only one plant was found in each locality.

Leontodon autumnalis L.
In wet places in the moors, Mingulay only.

Taraxacum lævigatum DC.
Forms belonging to this segregate were found in the old cultivated areas of both islands.

Sonchus oleraceus L.
As a weed of cultivation in the previously cultivated areas, Mingulay.

S. asper L.
On both islands, generally on the cliffs.

S. arvensis L.
In wet places, sandy cliffs, Mingulay Bay.

Calluna vulgaris L.
Surprisingly very scarce on both islands, though occurring more frequently on Berneray than on Mingulay; plants very dwarf.

Erica Tetralix L.
In sheltered spots, both islands but not common.

E. cinerea L.
Very rare, only on Mingulay.

Armeria maritima Willd.
Common on rocks and cliffs both islands.

Primula vulgaris L.
On banks and cliffs both islands, everywhere abundant.

Glaux maritima L.
On rocky bare patches on top of the cliffs in the west of Mingulay.

Anagallis arvensis L.
As a weed of cultivation in the keeper's garden.

A. tenella Murr.
Widespread all over both islands, reaching to the highest point on Mingulay. A white flowered form was also observed.

Erythræa umbellatum Gilib. var. *capitatum* Koch.
Not common and limited to the sandy cliffs in the east of both islands.

Lycopsis arvensis L.
On previously cultivated areas but not plentiful; on Mingulay only.

Myosotis cespitosa Schultz.
In a wet place beside a well in the old village, Mingulay.

M. arvensis Hill.
Common enough in waste ground in and around the old village, Mingulay.

M. versicolor Sm.
Also quite common in previously cultivated areas, Mingulay.
Veronica persica Poir.
In the waste ground beside the keeper's house.
V. arvensis L.
Chiefly on dry sandy banks and old dykes but not plentiful, Mingulay only
Euphrasia brevipila Burnat and Gremli.
Common enough, both islands.
E. micrantha Rehb.
Only recorded from Mingulay.
Bartsia Odontites Huds.
Common enough in wet places around the old habitations.
Pedicularis palustris L.
Rare, only recorded from Berneray.
P. sylvatica L.
Everywhere abundant, both islands.
Rhinanthus Crista-galli L.
In the old fields, Mingulay.
Pinguicula vulgaris L.
Common and generally distributed over both islands.
P. lusitanica L.
Very rare and confined to one station on the north slope ot Hecla.
Mentha arvensis L.
Old fields, Mingulay.
M. aquatica L.
In the marsh beside the keeper's house but the plants were too young to determine them with certainty.
Lycopus europæus L.
Common in, but restricted to, the above marsh.
Prunella vulgaris L.
Common, both islands.
Galeopsis Tetrahit L.
In the keeper's garden.
Lamium moluccellifolium Fr.
Also in the keeper's garden.
Plantago major L.
On waste ground in the vicinity of the old houses, both islands
P. lanceolata L.
Common on the cliffs and in the old fields, both islands.
P. maritima L.
Generally distributed over both the islands, though most abundant on the cliffs. In the west of Mingulay very dwarf specimens occur which form a close turf on top of the cliffs.
P. Coronopus L.
Also common on the rocks and cliffs, both islands.
Littorella uniflora Aschers.
Common on the margins of rocky and peaty pools, both islands
Chenopodium album L.
On waste places near the old village.
Polygonum aviculare L.
In the keeper's garden.
P. Persicaria L.
Occurs occasionally in old cultivated areas, Mingulay
Oxyria digyna Hill.
Rather an unexpected find; rare on the cliffs north of Bay Sletta, Mingulay.
Rumex obtusifolius L.
On waste ground beside the keeper's house.

R. crispus L.
Usually confined to the cliffs, both islands.

R. Acetosa L.
Common enough in the old fields, both islands.

R. Acetosella L.
Also in the old pastures.

Rumex sp.
This plant was growing abundantly in the gullies of the cliffs in the west of both islands. It resembles most closely *R. Acetosa* but is a much more robust plant all over. I sent pressed specimens (unfortunately rather spoiled by immersion in sea water) to J. F. G. Chapple, Hon. Sec. of the Botanical Society, who tells me that they have nothing to match it in the Herb. Druce, and he suggests that if more complete and mature material could be obtained it would be worth sending them to Danser or Rechinger. I hope to visit the islands again this summer and obtain further specimens.

Euphorbia Helioscopia L.
In the keeper's garden.

Urtica dioica L.
Everywhere near old habitations.

U. urens L.
Common as a weed of cultivation in the old fields, Mingulay Bay.

Salix aurita L.
Rare and confined to sheltered areas, both islands.

S. aurita x **S. repens.**
Only one plant was observed on Mingulay.

S. repens L.
Much more abundant than the latter, occurring generally over both islands, but again preferring sheltered areas.

Populus tremula L.
Very rare and confined to the sandy cliffs in the south of Mingulay Bay; plants dwarf and scrubby.

Orchis incarnata L.
Very rare in the marshes beside the keeper's house, Mingulay and near the landing place, Berneray.

O. purpurella Stphns.
Also in the marsh beside the keeper's house.

O. majalis Reichb., sub-sp. **occidentalis** Pugsl.
A recently discovered orchid of Ireland and the Hebrides. Found on Berneray only, in the marsh near the landing place.

O. elodes Gris. (=O. ericetorum Linton.)
Widespread on the moors both islands.

O. Fuchsii Druce.
Only in the marsh beside the keeper's house.

Iris Pseudacorus L.
Quite common in marshy places in the old fields, both islands.

Scilla verna Huds.
Generally distributed all over both the islands.

Juncus squarrosus L.
Not common and restricted to the north slope of Hecla.

J. communis L.
Common in wet places both islands.

J. bulbosus L.
Frequent in damp stony places in the moors, both islands.

J. articulatus L.
Quite common, both islands.

Luzula sylvatica Gaud.
Rare and local; on the grassy slope leading down to the cliffs in the west of Mingulay and again on the sandy cliffs, Mingulay Bay.

L. campestris DC.
Occurs occasionally in the old pastures.

L. multiflora DC.
Also occurs occasionally in dry moorland.

Triglochin palustre L.
Not uncommon in wet places by sides of streamlets, etc., both islands.

T. maritima L.
Rare in a marsh, Mingulay Bay only.

Potamogeton polygonifolius Pourr.
Common enough in streamlets, peaty pools and similar places, both islands.

Eleocharis palustris Roem. and Schult.
Common in the streamlets, both islands.

Scirpus cæspitosus L.
Abundant in the moors, both islands.

S. fluitans L.
Only observed in the streamlet running past the keeper's house.

S. setaceus L.
Rare on the sandy banks of the same streamlet.

Eriophorum angustifolium Roth.
Common on wet moorland and round the margins of peaty pools, both islands.

Schoenus nigricans L.
Common but local on rocky places, both islands.

Carex pulicaris L.
Common on heaths, grassy ledges, etc., both islands.

C. arenaria L.
On the dunes, Mingulay Bay.

C. echinata Murr.
Very common on damp moorland, both islands.

C. leporina L.
Only recorded from the marsh near the landing place, Berneray.

C. Goodenowii Gay.
Common, wet places both islands.

C. glauca Scop.
Apparently only observed on Mingulay where it is common.

C. binervis Sm.
Not uncommon on sheltered banks on the moors, Mingulay.

C. distans L.
Collected on Mingulay, but exact distribution not ascertained.

C. Oederi Retz.
Common on wet stony areas.

Anthoxanthum odoratum L.
Common in hill pastures, both islands.

Alopecurus geniculatus L.
Common in wet situations in the old fields, ditches, etc., Berneray; on Mingulay only beside the well of the old village.

Agrostis canina L.
Common enough, both islands.

A. alba L.
Common on the west side of Mingulay in damp situations; plants very dwarf.

A. stolonifera L.
Recorded from both islands; on Mingulay the var. **aristata** Sincl. also occurs. The latter plant was identified by Mr. Hubbard of the Royal Botanic Gardens, Kew.
Ammophila arenaria Link.
Common on the dunes, Mingulay Bay. On Berneray, a small isolated patch was observed on top of a cliff near Nisam Point in the south-east.
Deschampsia flexuosa Trin.
Rare on sheltered situations in the moors.
Holcus lanatus L.
Common locally, both islands.
Avena pubescens Huds.
On rocky and sandy cliffs in the east of both islands.
Arrhenatherum elatius Mert. and Koch.
On waste places and in old fields close to the village, Mingulay Bay.
Sieglingia decumbens Bernh.
Generally distributed in dry places, both islands.
Phragmites communis Trin.
Frequent in ditches and wet situations of both islands. It was noted that the plants growing in exposed stations were very dwarf, only attaining a height of 6-8 inches.
Cynosurus cristatus L.
Common in old pastures, both islands.
Koeleria gracilis Pers.
Common enough both islands on dry banks.
Molinia cærulea Moench.
Very abundant on both islands.
Poa annua L.
Near old habitations, both islands.
P. pratensis L.
Recorded from Berneray, only.
P. trivialis L.
On both islands, growing frequently among the Irises.
Glyceria fluitans Br.
Common in ditches and wet situations, Berneray. In spite of a careful search of likely places it was not found on Mingulay.
Festuca ovina L.
The var. **vivipara** occurs generally on both islands.
F. rubra L.
Occurs commonly on the cliffs near the sea.
Bromus hordaceus L.
On waste ground in the vicinity of the old habitations, both islands.
Brachypodium sylvaticum Roem. and Schult.
Confined to the sandy cliffs in the south of Mingulay Bay.
Lolium perenne L.
Common in the old pastures, both islands.
Agropyrum repens Beauv.
In a rocky cove north of Mingulay Bay, only.
A. junceum Beauv.
Rare on the dunes, Mingulay Bay.
Nardus stricta L.
Common but locally distributed, both islands.
Pteris aquilina L.
Uncommon both islands; confined to the dunes on Mingulay.
Blechnum Spicant With.
Fairly common on banksides and dry places in the moorland, both islands.

Asplenium marinum L.
Abundant on the sea cliffs of both islands.

Athyrium Felix-fœmina Roth.
Only a few plants observed on the banks of a streamlet near the landing place, Berneray.

Polypodium vulgare L.
Very rare in one station only on a bank in a sheltered depression, Mingulay.

Osmunda regalis L.
Only a few dwarf stunted plants were seen, and all but one were confined to the banks of the streamlet draining the south part of the valley opening into Mingulay Bay. The other was observed on a sea cliff in the south-east of Mingulay.

Ophioglossum vulgatum L.
Common in some of the previously cultivated areas, Mingulay Bay.

Equisetum sylvaticum L.
A few plants were observed on a ledge of the cliffs in the south of Mingulay Bay just below the keeper's house.

E. palustre L.
Common enough in wet sandy situations near the old village, Mingulay.

Selaginella selaginoides Gray.
Quite common on banks of ditches and streamlets, and on wet bare soil, both islands.

THE FREE-FLOATING MICROSCOPIC PLANT-LIFE OR PHYTOPLANKTON, OF THE LAKES OF THE ISLE OF RAASAY, INNER HEBRIDES, WESTERN SCOTLAND.

by

Benjamin Millard Griffiths, D.Sc., F.L.S.

1. The Isle of Raasay.

The Isle of Raasay lies off the east coast of Skye, from which it is separated by a channel which varies from half a mile to five miles in breadth. Eastward of Raasay is the mainland of Scotland some seven miles distant. The Isle is about fourteen miles long and from half a mile to three and a half miles wide. The Isle runs nearly due north and south, and consists of a long rocky ridge which rises to a height of 1,456 feet at the peak of Dun Caan. The eastern side is very steep but the western and southern slopes are more gentle. The ridge is furrowed by steep-sided basins and valleys in which most of the lakes lie. Almost the whole island is heathy moorland with a shallow, damp, peaty soil through which the bare rock emerges everywhere. Cultivatable ground is found in only a few spots mainly in the south. Natural woods of birch and alder occur on the sides of some of the glens, but the moor is mostly treeless. The climate is mild and the rainfall heavy. The population is small: a little sheep farming is done but arable farming is very slight.

Geologically the Isle consists of Jurassic rock in the south, Torridonian in the middle and Lewisian in the north. Considerable areas of granitic and basaltic rock occur in the Jurassic area. (For geology, see map of Geolog. Surv. Scotland, Applecross, Sheet 81; see also Lee and Buckman, 12; Davidson, 13.)

In the summer of 1935 Professor J. W. Heslop Harrison of the Department of Botany, Armstrong College (University of Durham, Newcastle Division), Newcastle-on-Tyne, extended an invitation to the staff of the Department of Botany (University of Durham, Durham Division), Durham, to join the

TABLE I.

	Rock.	pH	Total Hardness.	Size in yards.	Height O.D.
1. Oskaig No. 1.	Granitic	5.7	0.6	30 × 30	300
2. " " 2....	"	7.0	1.0	50 × 30	300
3. " " 3....	"	7.1	2.5	50 × 50	350
26. Carn nan Eun	"	6.2	2.05	100 × 50	600
29. Storab....	"	6.5	3.7	200 × 75	800
14. Meal Daimh	Basaltic	7.1	2.15	175 × 75	1070
9. Eadar da Bhaile	Jurassic	7.2	2.95	400 × 100	200
10. Rathaid	"	7.8	3.9	350 × 100	100
16. Meilich	"	7.3	2.55	880 × 120	1058
17. Mna	"	6.9	1.25	700 × 100	1000
36. Chadha charnaich	"	8.2	5.0	500 × 75	400
12. Groidean	Torridonian	5.2	1.95	150 × 20	100
19. Uachdair	"	6.9	3.4	450 × 200	200
21. Beag	"	6.8	3.15	200 × 75	200
22. Cuilche	"	7.1	3.15	200 × 75	200
24. Bronn....	"	7.1	3.25	200 × 100	250
31. Dubhan	Lewisian	7.3	3.3	120 × 30	550
32. East Eabhan	"	4.7	0.9	50 × 50	600
34. Am Feur	"	7.3	2.45	100 × 20	550
35. Mallaichte	"	4.3	2.8	80 × 80	550
6. Mhuilinn	Artificial	6.4	1.0	150 × 100	100
7. Reservoir	(Jurassic)	6.9	1.15	100 × 30	100

expedition which he was organising to investigate the flora and fauna of Raasay. The writer and Miss K. M. Chalklin, M.Sc., took advantage of the invitation and carried out the survey of the lakes, the results of which are set out below. The investigation was confined to the free-floating alga-flora of the lakes, and did not include the flora of bogs, boggy pools and wet surfaces of rock and earth. The latter flora is reserved for future study.

2. The Lakes of Raasay.

The total number of lakes on Raasay is less than thirty. They are all small, the two largest, namely Meilich and Uachdir, being only about twenty acres in area (8.0 hectares). The smallest lakes which were examined were the three Oskaig lakes which are less than an acre in area. The only lakes of any size which were not examined were Mor on the island of Fladday and Ghrunnd at the extreme north of Raasay. Twenty-two lakes were examined, of which five lie on areas of granitic rock, one on Basaltic, five on Jurassic, five on Torridonian, four on Lewisian, and two artificial lakes, namely a mill pool and a reservoir, lying on Jurassic. The following Table 1 gives the name and collection-number of each lake, the kind of underlying rock, the pH and hardness of the water, the size in yards, and the height above sea level. The pH was determined on the spot with a B.D.H. Lovibond Comparator, and the hardness was determined on samples of water taken to the laboratory at Inverarish, which Professor J. W. Heslop Harrison put at our disposal. The lake given as " Carn nan Eun " is not marked on the 6-in. Ord. Surv. map and is named by the writer after the hill it is on. East Dubhan is also named by the writer as it is marked on the map but not named thereon.

Most of the lakes are under ten feet (three metres) or so in depth. Lakes Cuilche, Bronn, East Dubhan, Mhuilinn and the Reservoir. may be slightly deeper, and Rathaid, Meilich, Mna and Uachdair may be twenty feet or over. The lakes of Raasay are therefore small and few, especially when compared with those of the isles of the Outer Hebrides, such as the Isle of Lewis (see Murray and Pullar, 6 ; in particular Lake Fadagoa,

p. 209, to which so many references are made by Messrs. W. & G. S. West, II). The water of all the lakes was clear and in most cases colourless or with a slightly brownish tinge. The only definitely brown-water lakes were the two artificial lakes and three lakes on the Lewisian, viz. Dubhan, Am feur and Mallichte, which lie among peat deposits. Owing to the clearness of the water and the shallowness of the lakes, the bottom was usually visible. Most of the lakes have rocky sides and bottoms, but some are peaty, e.g. Groidean, Cuilche, Am feur, and Mhuilinn. Eadar da Bhaile and Chadha charnaich are partly sandy.

The rocky basins are unfavourable for the development of macrophytic litoral vegetation, and it was very seldom that vegetation occurred in continuous masses or fringes. Exceptions were seen in the cases of Cuilche, Bronn, and Chadha charnaich, and in Mhuilinn. In Cuilche (which means "reedy") there was a broad and semi-continuous fringe of *Phragmites*, succeeded by a complete zone of *Nymphæa alba* (small form) in front of which was a narrower zone of *N. alba* (larger form) surrounding a small central circular area of open water. The basin was partly in peat. The only other occurrence of *Phragmites* was in Rathaid, where it was found in small amount near the outflow end. In Bronn there was a scanty fringe of alder trees on the shore, a feature shared with the two artificial pools, Mhuilinn and the Reservoir, but the other lakes were conspicuously devoid of trees on their shores. In Bronn, the basin was rocky and the litoral vegetation was very scanty but the centre of the basin was occupied by a broad circular zone of the small form of *Nymphæa alba*, in front of which was a narrower zone of the larger form surrounding a circular area of open water, as in Cuilche. In Chadha charnaich there were large areas of vegetation, and in Mhuilinn most of the basin was occupied by *Potamogeton polygonifolius*. In contrast to these relatively weedy lakes was East Dubhan whose basin was of bare pinkish Lewisian rock with only a few plants of *Lobelia Dortmanna* growing in the cracks and hollows.

The principal macrophytes occurring in the Raasay lakes were, in order of frequency, as follows:— *Lobelia Dortmanna*

and *Potamogeton polygonifolius* occurring in 15 out of the 22 lakes examined; *Myriophyllum alterniflora* and *Menyanthes trifoliata* in 12; *Nymphæa alba* and *Carex ampullacea* in 11; *Scirpus palustris* and *Ranunculus Flammula* in 8; *Scirpus fluitans*, *Equisetum limosum* and *Sphagnum* in 7; *Littorella lacustris* in 6; *Juncus bulbosus* and *Sparganium natans* in 5. *Isoetes* was found in Uachdair and Beag; *Phragmites* in Cuilche and Rathaid; *Comarum palustre* in Chadha charnaich (see also Harrison, J. W. H., 14).

A further characteristic of the Raasay lakes was their relatively low pH, which tended to vary from about neutral to distinctly acid. The lakes on the Jurassic rock tended to have the higher pH and one of them, Chadha charnaich, had the highest of all 8.2. This lake lies on a great shelf of Jurassic rock below the peak of Dun Caan, and is on the site of a large land-slip. The bottom of the lake is partly rocky but mostly sandy. Macrophytic vegetation occurs in large patches and the submerged stones are everywhere covered with thick cushions of *Schizothrix*.

The water of the Raasay lakes was also characterised by a low dissolved salts content as expressed in degrees of hardness. The greatest hardness, which was found in Chadha charnaich, was only 5 degrees, and the rest of the lakes were all lower than 4.

These features of the lakes, namely rocky basins, neutral to acid water, softness and only slight peatiness, are the features which Messrs. West state are favourable for the development of a phytoplankton dominated by desmids (West, W. & G. S., 10, p. 201), and their statement is fully confirmed by the results of our observations. The Raasay lakes are mostly of the oligotrophic type of Naumann (Thienemann, 8, p. 200) and the eutrophic and dystrophic types are not fully developed, although Cuilche and Bronn may show some slight tendency towards eutrophification, and Dubhan, Am feur and Mallaichte towards the dystrophic type.

3. The Freefloating Microflora or Phytoplankton.

Collections of plankton were taken by means of a conical net made of No. 20 bolting silk, and fitted with a collecting

tube to retain the catch. The net was used either by drawing it to and fro in the water at the end of a long rod from the shore, or by fixing it into a specially designed biplane otter-board, and sending the apparatus out from the shore over the deeper water. The apparatus is workable only where the shore is sufficiently free from encumbrances to permit uninterrupted towing, but fortunately most of the Raasay lakes have rocky shores which are devoid of tall or dense vegetation, so the apparatus was used successfully on all the lakes except Cuilche, Bronn and the two artificial lakes. In most cases both methods of collection were used and it was found that there was no qualitative difference between the catches but if anything the rod collections were slightly greater in quantity.

In the lakes Carn nan Eun, Storab, East Dubhan, Groidean, and the Reservoir, squeeze collections of bentho-plankton were taken from the submerged *Sphagnum* moss at the side, as well as the limnoplankton catches taken with the net. A comparison between the microphyta of the litoral and of the open water is given in a later part of this paper.

The plankton showed the features characteristic of soft-water lakes of the western type as described by Messrs. West (10, p. 201), namely scantiness in the numbers of algæ present, combined with a marked dominance of many species of desmids. In spite of the smallness of the Raasay lakes, there was a conspicuous desmid-plankton, comprising about 75 per cent of the whole phytoplankton, and numbering some 99 species. Of these the genus *Staurastrum* was represented by 33 species and varieties, *Cosmarium* by 14, *Micrasterias* by 9, *Euastrum* 10, *Xanthidium* 7, and *Arthrodesmus* by 8. The lakes showed great differences in their desmid floras, and the most widely distributed species were *Cosmarium depressum* found in 9 lakes and *Staurastrum anatinum* and *Xanthidium antilopeum* in 8. The richest desmid flora occurred in Storab with 43 species and varieties and Carn nan Eun with 41, both lakes being situated on granitic rock. In addition to the limno-plankton desmids there also occurred some fifteen bentho-planktonic desmids derived from the fringing *Sphagnum* moss, and including *Netrium* with 3 species, *Euastrum* 3, *Cosmarium* 5, *Staurastrum* 2; and 1 each of *Penium* and *Closterium*,

bringing the total desmid flora of the lakes to 114 species and varieties.

Messrs. West (10, P., p. 201-2) distinguish three classes of desmids according to their areal distribution, namely a "western" group of species confined to the older geological strata of the western areas of the British Isles; a second group not confined to but most abundant in the western areas, and a third group of more or less ubiquitous species. An examination of the list of Raasay desmids shows that 22 or about 20 per cent of the desmid flora consists of western or semi-western types. There are 12 species of the western type, viz. *Docidium undulatum*, *Cosmarium monomazon* var., *Micrasterias radiata*, *M. pinnatifida*, *Staurastrum aversum*, *St. Brasiliense* var. *Lundellii*, *St. bacillare*, *St. Cerastes*, *St. forficulatum*, *St. longispinum*, *St. sexangulare*, *St. subgracillimum*. There are 10 species of the semi-western type, viz. *Netrium oblongum*, *Cosmarium connatum*, *C. ovale*, *Euastrum crassum*, *E. pulchellum*, *E. pinnatum*, *Micrasterias rotata*, *Staurastrum anatinum*, *St. Arachne*, *St. furcatum*. Most of the desmids of the western type were confined to lakes which were situated on granitic rock, but the semi-western types were much less closely restricted.

The CHLOROPHYCEÆ (exclusive of Desmids) were represented by 4 filamentous species and 12 colonial species. The most frequent were *Mougeotia* which occurred in 10 lakes, and *Glœocystis* in 9. An interesting species was *Crucigenia rectangularis* var. *irregularis* which was found in 5 lakes (see West, W. & G. S., 10, p. 170). *Eudorina*, *Pediastrum Tetras*, *Dictyosphærium* and *Richteriella*, occurred solely in Bronn, and their presence possibly points towards eutrophication in that lake.

The BACILLARIEÆ were represented by 4 genera, but except in the case of *Asterionella* in Rathaid, diatoms were neither abundant nor frequent.

The CYANOPHYCEÆ included 7 species, of which *Anabæna Lemmermanni*, and also *Lyngbya bipunctata*, occurred in abundance in the larger and deeper lakes but not in sufficient quantity to discolour the water. The most widely distributed

species was *Cœlosphærium Kützingianum*, which occurred in 8 lakes, and *Anabæna Lemmermanni* in 6.

The PERIDINIEÆ included 4 species. *Ceratium hirundinella* was found in 8 of the larger lakes, usually in association with *Anabæna*. *Ceratium cornutum* occurred in 9 of the smaller lakes. *Ceratium curvirostre* was found only in the very small lakes Oskaig No. 1 and Oskaig No. 2. It is a characteristic " western " species, associated with areas of ancient rock. *Peridinium Willei* was found only in Meilicht and Mna. It also tends to be confined to soft-water lakes.

The phytoplankton of the largest lakes, namely Meal Daimh, Rathaid, Meilicht, Mna, and Uachdair, differed from that of the smaller in the predominance of algæ other than desmids. In these cases the desmid flora was definitely subordinate to a flora of Peridinieæ, Cyanophyceæ or Bacillarieæ, and but for the desmids which were present though in small quantity, the plankton bore a resemblance to that of the hard-water alkaline lakes of the newer rock areas of the lowlands.

Messrs. West (10, p. 196) consider that an area is rich in desmids when 150 species or more are found in it. The total of 114 plankton desmids for Raasay is less than the required number but it is the total for the lakes only and does not include the species occurring in bogs, boggy pools and on the surface of damp rocks. The fact that some 15 desmids other than planktonic were collected from the fringing *Sphagnum* moss of some of the lakes, and that some 20 per cent of the total desmid flora is " western " in type, makes it probable that an investigation of habitats other than the lacustrine would yield the total of species required to constitute a " rich " desmid flora. The probabilities are therefore that the desmid flora of Raasay is of the same type as that of the rest of the north-western Scottish districts, and is part of the rich desmid flora which is characteristic of ancient rock areas in Britain and elsewhere.

The Phytoplankton of the Lakes of Raasay.

The lakes are indicated by reference numbers as follows:— 1. Oskaig No. 1, 3. Oskaig No. 2, 5. Oskaig No. 3, 29. Storab, 26. Carn nan Eun, 14. Meal Daimh, 9. Eadar da Bhaile, 10.

Rathaid, 16. Meilich, 17. Mna, 36. Chadha charnaich, 12. Groidean, 19. Uachdair, 21. Beag, 22. Cuilche, 24. Bronn, 31. Dubhan, 32. East Dubhan, 34. Am feur, 35. Mallaichte, 6. Mhuilinn, 7. Reservoir. B. Basaltic. A. Artificial, on Jurassic.

4. The Limno—and Benthoplankton.

A comparative study of the microflora of the open water (limnoplankton) and that of the submerged or semi-submerged vegetation of the litoral region (benthoplankton) was carried out on five of the lakes of Raasay, namely Carn nan Eun, Storab, East Dubhan, the Reservoir, and Groidean. The object of the study was to ascertain the relationship between the microflora of the two sections of the lacustrine habitat, which though visibly distinguishable are nevertheless in aqueous continuity. A collection of limnoplankton was taken from the open water of each lake and at the same time a squeeze collection of benthoplankton was made from the submerged masses of Sphagnum moss fringing the shore.

The microflora of each lake was analysed into four classes namely 1, those algæ which occurred only in the limnoplankton; 2, those found in both the limnoplankton and the benthoplankton; 3, those found in the benthoplankton of one or other of the five lakes but which were also encountered in the limnoplankton of other lakes on Raasay; and 4, those which occurred only in the benthoplankton of the five lakes.

The contents of the five lakes were as follows:—

I. Carn nan Eun.

In open water only: *Euastrum ansatum*, *Cosmarium contractum*, *C. monomazum* var., *C. reniforme*, *Cosmocladium pusillum*, *Xanthidium antilopeum*, *Staurastrum anatinum*, *St. Arachne* var., *St. bacillare* var., *St. brachiatum*, *St. forficulatum*, *St. gracile* var., *St. longispinum*, *St. muticum*, *St. sexangulare*, *St. subgracillimum*, *Sphœrozosma Aubertianum* var., *Gymnozyga moniliforme*, *Hyalotheca dissiliens*, *H. mucosa*, *Ceratium cornutum*.

In open water and in moss: *Euastrum pinnatum*, *Arthrodesmus Incus*, *Glœocystis gigas*, *Staurastrum cuspidatum*.

In moss but also in open water of other lakes: *Netrium Digitus*, *Pleurotænium Ehrenbergi*, *Tetmemorous granulatus*, *Euastrum crassum*, *E. pectinatum*, *Micrasterias truncata*, *Cosmarium ornatum*, *Xanthidium armatum*, *Pinnularia* sp.

In moss only: *Netrium interruptum*, *N. oblongum*, *Closterium didymotocum*, *Euastrum ansatum* var., *Cosmarium tetraophthalmum*, *Straurastrum tetracerum*, *Pediastrum angulosum* var.

II. Storab.

In open water only: *Cosmarium contractum* var., *C. depressum*, *C. moniliforme*, *C. monomazum* var., *Xanthidium antilopeum*, *Arthrodesmus triangularis* var., *Staurastrum anatinum*, *St. apiculatum*, *St. brevispinum*, *St. Brasiliense* var., *St. cuspidatum*, *St. Dickiei* var., *St. forficulatum*, *St. furcatum*, *St. furcatum* var., *St. gracile* var., *St. longispinum*, *St. sexangulare*, *St. subgracillimum*, *St. Tohopekaligense* var., *St. tumidum*, *Sphærozosma Aubertianum* var., *Gymnozyga moniliforme*, *Hyalotheca dissiliens*, *H. mucosa*, *Desmidium aptogonum*, *Glœocystis gigas*, *Synechococus* sp.

In open water and in moss: *Xanthidium armatum*, *Arthrodesmus Bulnheimii* var., *Staurastrum Cerastes*, *St. corniculatum* var., *Ceratium cornutum*.

In moss but in open water of other lakes: *Tetmemorus granulatus*, *Euastrum crassum*, *E. pectinatum*, *Micrasterias denticulata*, *M. pinnatifida*, *M. truncata*.

In moss only: *Cosmarium Botrytis*, *Euastrum crassum* var., *E. pectinatum* var., *Staurastrum Arachne*.

III. East Dubhan.

In open water only: *Mougeotia* sp., *Arthrodesmus Incus* var., *Staurastrum anatinum*, *St. paradoxum* var., *Spondylosium tetragonum*, *Botryococcus Braunii*, *Merismopedia tenuissima*, *Dinobryon cylindricum*, *Tabellaria* sp., *Ceratium cornutum*.

In open water and in moss: *Netrium Digitus*, *Euastrum elegans*, *Arthrodesmus Bulnheimii* var., *A. Incus* var., *Staurastrum brachiatum*, *St. connatum*.

In moss but in open water of other lakes: *Euastrum ansatum*

In moss only: *Penium minimum* var.

IV. Groidean.

In open water only: *Mougeotia* sp., *Xanthidium antilopeum* var., *Cosmarium contractum*, *Staurastrum gracile*, *Anabæna Lemmermanni*, *Gomphosphærea aponina*, *Dinobryon divergens*, *Ceratium hirundinella*.

In open water and in moss: *Micrasterias truncata*, *Arthrodesmus octocornis*, *Xanthidium antilopeum* var., *Staurastrum paradoxum*, *Glœocystis gigas*, *Botryococcus Braunii*.

In moss but in open water of other lakes: *Euastrum dubium*, *Staurastrum brachiatum*, *Synechococcus* sp.

In moss only: *Cosmarium sphagnicolum*.

V. The Reservoir.

In open water only: *Mougeotia* sp., *Euastrum pinnatum*, *Micrasterias Americana*, *M. pinnatifida*, *M. truncata*, *Staurastrum dejectum*.

In open water and in moss: *Cœlosphærium Kutzingianum*.

In moss but in open water of other lakes: *Tetmemorus granulatus*, *Pinnularia* sp., *Tabellaria* sp.

In moss only: *Netrium Nægelianum*, *Closterium didymotocum*, *Cosmarium conspersum* var., *C. subcucumis*, *Crucigenia quadrata*.

The alga flora of the five lakes comprises 93 species and varieties of which 43 are confined to the open water, 32 are common to the open water and the moss, and 18 are found only in the moss. There is apparently a distinct difference between the open water flora or limnoplankton and the moss flora or benthoplankton, even though there is also an intermediate flora amounting to more than a third of the total plankton flora.

The difference between the limno- and bentho-plankton has, however, been noted by Messrs. West (10, p. 177) for the British freshwater phytoplankton as a whole. They distinguish three classes of planktonts, viz. "P" species which are "exclusively confined to the plankton," "Pv" varieties which are "exclusively plankton varieties of species which frequently occur in other situations", and "p" species which are "more abundant in the plankton than elsewhere." (In Messrs. West's nomenclature, "plankton" is equivalent

to our limnoplankton, and the terms " other situations " and " elsewhere " correspond to our benthoplankton.) An analysis of the flora of the five lakes in terms of Messrs. West's classification gives the following results:—

Species occurring	P	Pv	p	Plank-tonic	Else-where	
in open water only	2	2	8	12	31	43
in open water and in moss			2	2	30	32
in moss only			0	0	18	18
	2	2	10	14	79	93

It is evident from the above results that although the open-water flora contains more of Messrs West's planktonic forms than the intermediate and the moss flora, nevertheless the large majority of forms, 79 out of 93, are not truly planktonic. The open-water flora is composed not of true or what one might call obligate limnoplanktonts but only of facultative limnoplanktonts or benthoplanktonts which have drifted out from the litoral into the open water. An examination of the plankton of the whole of the Raasay lakes shows that 34 " planktonic " species occur, or 22 per cent., made up as follows:—

P species, 9: *Micrasterias Murrayi*, *Botryococcus protuberans*, *Sphærocystis Schrœteri*, *Anabæna Lemmermanni*, *Lyngbya bipunctata*, *Merismopedia tenuissima*, *Ceratium curvirostre*, *Ceratium hinrundinella*, *Peridinium Willei.*

P v varieties, 6: *Xanthidium antilopeum* var. *depauperatum*, *Xanthidium antilopeum* var. *hebridiarum*, *X. controversum* var. *planctonicum*, *Staurastrum Arachne* var., *curvatum*, *St. lunatum* var. *planctonicum*, *St. megacanthum* var. *scoticum*.

p species, 19: *Euastrum verrucosum* var. *reductum*, *Micrasterias radiata*, *M. Sol*, *Cosmarium depressum*, *Staurastrum anatinum*, *St. aversum*, *St. Brasiliense* var.

Lundellii, St. brevispinum, St. dejectum, St. longispinum, St. sexangulare, Sphærozosma Aubertianum var. *Archeri Ankistrodesmus spiralis, Dictyosphærium pulchellum, Botryococcus Braunii, Asterionella formosa, Dinobryon cylindricum, D. divergens, Ceratium cornutum.*

The higher percentage of planktonic algæ in the 22 lakes is due to the fact that the 5 lakes are all small, whereas the full 22 includes all the larger ones as well. The presence of planktonic forms depends mainly on the size of the lake. In the smaller type of lake the community of planktonts is not differentiated into limno- and bentho-plankton but consists mainly of litoral forms which have drifted out into the open water. In the larger lakes true limnoplanktonts appear in addition to the facultative limnoplanktonts.

The larger lakes of Raasay are of relatively small size compared with many of the other lakes of Britain, and the percentage of planktonic forms for the whole of the British freshwater phytoplankton amounts to some 26 per cent of the flora. In the table below the different percentages are compared:—

	P	Pv	p	Planktonic	Elsewhere	
Raasay, 5 smaller lakes	2	2	10	14	79	93
%	2.1	2.1	10.7	15	85	100
Raasay, all lakes, 22	9	6	19	34	115	149
%	6.0	4.0	12.6	22.6	77.4	100
British, all lakes	53	30	87	167	456	623
(West W.&G.S.,10) %	8.7	4.2	13.9	26.8	73.2	100

It would appear therefore that the lakes of Raasay are for the most part too small to show a true limnoplankton, and the open water flora is mainly litoral in origin and benthic in character.

5. Notes on Special Species.

1. **Micrasterias Murrayi**, W. & G. S. West.

M. Murrayi was first found in Loch Ruar, Sutherland, (West, W. & G. S., Brit. Desmid., 2, 1905, p. 93, Pl. 45, Figs. 1-3). Since that time it has been reported from Switzerland, Russia, Bavaria and Spain, (see Allorge, V. & P., I, p. 351, Pl. 7). Allorge regards it as a variety of *Micrasterias Sol* (Ehr.) Kutz., (*M. radiosa* Ralfs). In Raasay, it also appears to be a derivative of *M. Sol*, occurring along with forms which are intermediate, together with typical *M. Sol*. It was found in Oskaig No. 3 and in Meal Daimh, and in both cases was accompanied by *M. Sol*. Oskaig No. 3 is a small tarn on granitic rock and Meal Daimh is a lake of fair size lying on basalt on a shoulder of Dun Caan at a height of over a thousand feet. The accompanying figures show a specimen of *M. Murrayi* from Meal Daimh (Fig. A), and an intermediate form, one semi-cell being *M. Murrayi* in type and the other semi-cell being *M. Sol* (Fig. B).

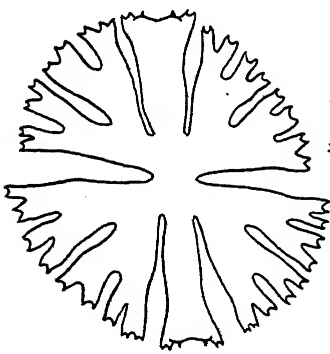


Fig. A.

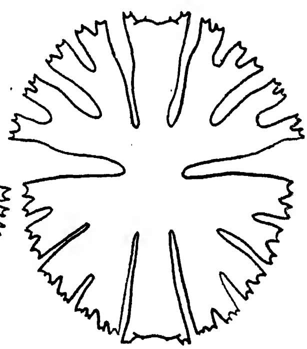
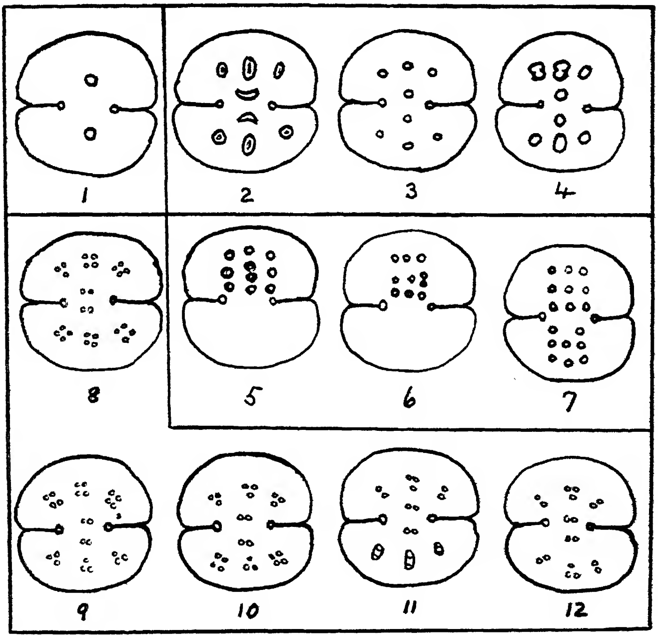


Fig. B.

2. **Cosmarium monomazum** Lundell var. nov. **polysticta**.

C. monomazum Lund. varies greatly in the character of the markings on the face of the semi-cell. The type form has one central nodule (see Fig. 1); the variety *polymazum* Nordst. has three nodules arranged in one line across the

middle of the semi-cell, and one nodule just above the isthmus (see Figs. 2, 3, 4); the American variety *tristichum* West, W. & G. S., has three rows of nodules (see Figs. 5, 6, 7). In Raasay the desmid was found in Carn nan Eun and Storab, but the type of marking differed from both *polymazum* and *tristichum*, and is here described as a new variety, *polysticta*. The markings consist of groups of from two to four granules, the groups being arranged in each semi-cell in one row of



three groups and one group at the isthmus (see Figs. 8, 9, 10, 11, 12). In Fig. 11 is shown a specimen in which the pairs of granules are placed on an oval basal elevation rather similar in appearance to the ornamentation shown in Fig. 2.

Diagnosis: *Cosmarium monomazum* Lundell var. nov. *polysticta*. Semicellula tribus nidis vel duarum, vel trium, vel quattuor parvarum papillarum ornata, cum alio nidc

duarum parvarum papillarum circa isthmum; in Caledonia in lacubus insulæ Raasay.

COSMARIUM MONOMAZUM Lund., semi-diagramatic figures showing only arrangement of markings on the face of the cell. FIG. 1, Type form after Messrs. West, II, vol. 3, Pl., 76, Fig. 12. FIG. 2, var. *polymazum* Nordst., II, vol. 3, Pl. 76, Fig. 14. FIG. 3, ditto, Fig. 13. FIG. 4, var. *polymazum* after Taylor, W. R., 7, Pl. 54, Fig. 4. FIG. 5, var. *tristichum* West W. & G. S., after Messrs. West, 9, p. 305, Fig. 4. FIG. 6, ditto. FIG. 7, ditto. FIG. 8, var. *polysticta*, specimen from Carn nan Eun. FIG. 9, ditto. FIG. 10, ditto. FIG. 11, specimens from Storab. FIG. 12, ditto.

3. **Staurastrum anatinum** Cook & Wills var. **biradiatum.** West, W. & G. S., forma nov. MAJOR.

Staurastrum anatinum was found in eight of the Raasay lakes. A biradiate variety occurred in Carn nan Eun and Storab, unmixed with the type-form in the former and mixed in the latter. The biradiate variety was not quite the same as var. *biradiata* West W. & G. S. It differed from the type only in the absence of one of the three processes of the semicell. The size of the cell, the divergence of the processes, and the ornamentation of the wall was the same as in the type.

In conclusion I wish to offer my hearty thanks to Professor J. W. Heslop Harrison for his kindness in extending an invitation to accompany the Armstrong College Expedition to Raasay, and for his generosity in putting at our disposal the facilities for carrying out the work, and for accommodation on the Isle. I am also much obliged to Dr. Nellie Carter for assistance with some of the desmids, and to Dr. W. B. Crow in regard to Cyanophyceæ. I am obliged in special measure to Miss K. M. Chalklin who carried out the pH observations and the determinations of the hardness of the water.

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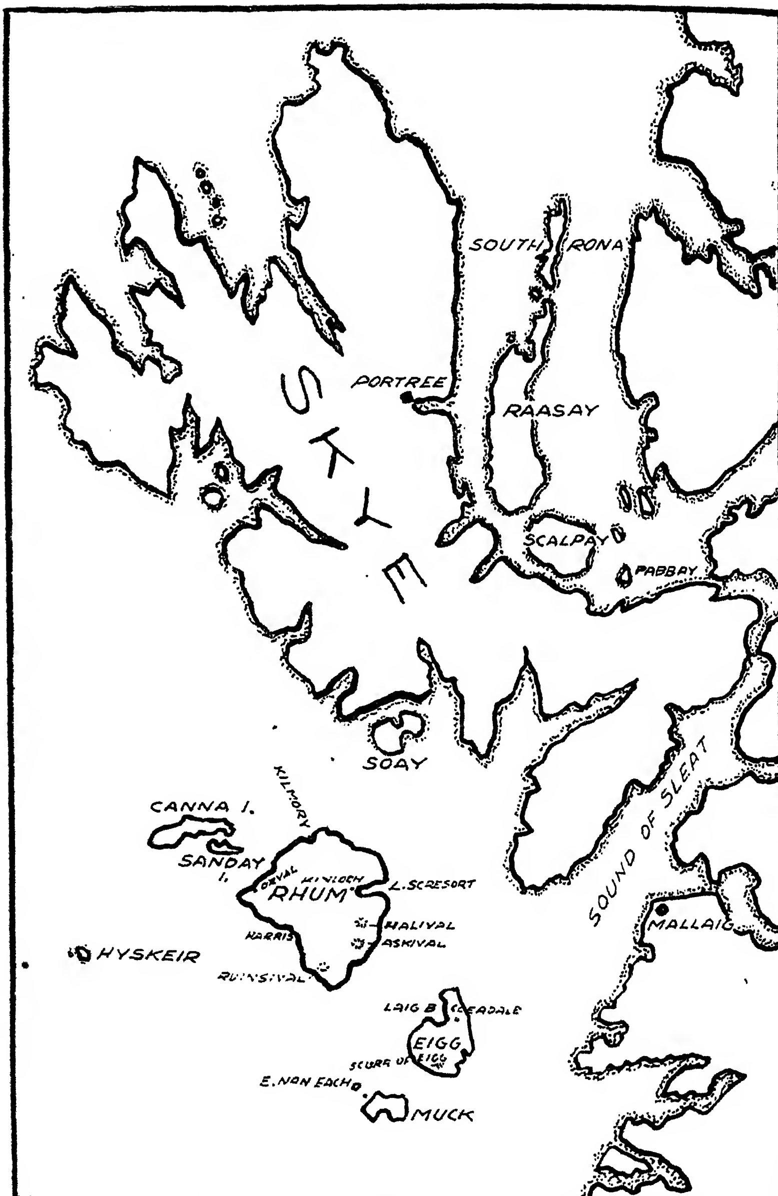


Fig. 1. Map of Skye and the Neighbouring Islands.

THE FLORA OF THE ISLANDS OF RHUM, EIGG, CANNA, SANDAY, MUCK, EILEAN NAN EACH, HYSKEIR, SOAY AND PABBAY.

Edited by J. W. Heslop Harrison, D.Sc., F.R.S.

Since the task of preparing a Flora of the Inner and Outer Hebrides was undertaken by the Department of Botany, King's College, University of Durham, in 1934, the necessary research work has been prosecuted with unceasing vigour. Beginning with the exploration of Raasay and Rona in 1934, and our investigations on Barra and South Uist in 1935, the work has extended year by year until the whole of the major islands in both groups, and very many of the smaller ones, have been surveyed by numerous parties.

Last year, (1938), no fewer than five expeditions were organised, two to explore the Inner, and three the Outer Isles. The earlier of the two visits to the Inner Islands took us to Muck, Eilean nan Each and Eigg, whilst the later, and much more sustained effort, enabled us not only to subject Rhum to a very thorough examination, but also to extend our previous work on Eigg, Canna and Sanday, and finally to study the plants on the Hyskeir reef.

As we had already made a prolonged stay on Soay in 1937, and had also taken advantage of an opportunity to investigate Pabbay the same year, we had thus completed an exploration of the whole of the islands lying adjacent to Skye which had not been discussed from the botanical standpoint in our " Flora of Raasay and the Adjacent Islands."* The results of our work,† representing several seasons' efforts, are set out here.

The personnel of the various expeditions did not differ greatly from that which participated in the earlier work, and as far as the flowering plants and ferns are concerned, the following are responsible not only for the very arduous, and sometimes, dangerous work in the field, but also for the preparation of this paper:

*Proceeding of the University of Durham Philosophical Society, Vol. IX., Part V, pp. 260-304.

†It should be understood that this report is of a preliminary nature. The complete results will appear in our comprehensive Flora of the Inner and Outer Hebrides which will be published later.

Professor J. W. Heslop Harrison, D.Sc., F.R.S.
Miss K. B. Blackburn, D.Sc.
Miss E. Bolton, M.Sc.
Miss H. B. Bond, B.Sc.
Mr. W. A. Clark, B.Sc., Ph.D.
Mr. R. B. Cooke.
Miss H. Heslop Harrison, M.Sc.
Mr. J. Heslop Harrison.
Miss B. H. Todd, B.Sc.

Amongst these Prof. J. W. Heslop Harrison was responsible for the Salices and Orchidaceæ, Professor Heslop Harrison and Miss E. Bolton for the Rosae, Dr. K. B. Blackburn for the Violaceæ, and Miss H. Heslop Harrison for the Gramineæ.

In additon, Mr. S. I. Tomkeieff, M.Sc., studied the Geology, whilst Mr. W. Campion formed a very valuable asset in the whole of our activities.

The whole of the islands explored are, of course, in Watsonian Vice-county 104. A glance at the map will reveal that Pabbay lies three miles north east of Broadford, and Soay due south of the Cuillin Mountains in Skye, from which it is separated by Soay Sound. The remaining islands, forming a kind of interrupted band, stretch to the south of, and parallel to, Skye and are divided therefrom by the deep Cuillin Sound; they belong to the small Islands Parish of Inverness-shire.

Rhum, Eigg, Canna and Muck call for no further remarks as to their positions, but it should be noted that Eilean nan Each lies just north west of the Isle of Muck, whilst Coralag is a tiny islet to the north of the same island. The Hyskeir reef will be found on the map about twelve miles due west of the Harris area of Rhum.

Geologically speaking, the islands of the Small Islands Parish reveal a varied and interesting assemblage of rocks of which the most noteworthy are of igneous origin.

Of the sedimentary rocks, the oldest belong to the Torridonian strata and occur as red sandstones and shales in the northern and eastern districts of Rhum. They are affected by a system of powerful thrust planes, which probably form the S.W. extension of the Moine thrust belt.

A considerable time-gap separates the Torridonian rocks from the other sedimentary rocks of this island group. The Jurassic sandstones, shales and thin limestones, which form the basement of the northern half of Eigg, and which cover a small area of Muck, are all that remain of these younger sedimentary rocks.

Fig. 2. The Party on the Path to Dibidil.

A far greater part of the total area of the islands is occupied by igneous rocks of the Tertiary age. These may be divided into two groups (1) extrusive and (2) intrusive.

(1). The extrusive rocks belong to the early period of igneous activity and are represented by basalt, mugearite and pitchstone lavas, and beds of volcanic agglomerate and tuff. Canna and Sanday are made entirely of volcanic rocks, and Eigg and Muck almost entirely. On Rhum, the lavas are found only as small isolated patches. In one of these—a mugearite lava-flow—a fragment of fossil tree was found in 1938. This discovery confirms the evidence of fossil flora, found in the interbasaltic beds of Mull and elsewhere, as to the Tertiary age of the eruptions in this region.

The remarkable hill called the Sgurr of Eigg is probably a remnant of a columnar pitchstone lava, infilling a valley excavated in the underlying basalt lavas. A similar columnar pitchstone forms the small island of Oigh-sgeir (Hyskeir), and this may represent a westward extension of the lava-flow of the Sgurr.

(2). With the exception of later minor intrusions in the form of basalt dykes, the intrusive rocks of the islands are confined to the island of Rhum. These rocks can be subdivided, according to their composition, into three groups—ultrabasic, basic and acid.

The ultrabasic magma was intruded first, and solidified as a complex banded laccolite. Highly dissected by denudation, this laccolite forms the group of high hills of the S.E. district of Rhum (Barkeval, Hallival, Askival, etc.). The well-exposed slopes of these hills present a striking appearance with their thick alternating bands of light and dark tone. The dark bands are formed by peridotite (olivine rock) and the light ones by allivalite (olivine and basic plagioclase).

The ultrabasic was followed by a basic magma, which was intruded into the complex laccolite in thick sheets and has consolidated as a coarse-grained banded eucrite (a variety of gabbro composed of basic plagioclase, augite and olivine).

The acid magma came at a still later date. It is represented by sheets of felsite intruded into the complex laccolite and by a large stretch of granophyre (acid feldspar and quartz) which occupies the western portion of Rhum. In many places the contact between this granophyre and the eucrite and peridotite, into which it is intruded, is sharp and clearly marked, but more often intermediate hybrid rocks were formed through the action of acid magma on basic and ultrabasic rocks.

Basalt dykes, marking later minor intrusions, cut right through the earlier volcanic and plutonic rocks and are found,

not only on Rhum, but on other islands of the group, particularly on Muck where they intersect the basalt lavas.

The islands were affected by glaciation, and the orientation of the glacial striæ on rocks indicates that the ice came from the E.S.E. direction, i.e. from the mainland. Ice-smoothed and striated rocks and deposits of boulder clay in the valleys testify to the intensity of the former glaciation to which this region has been subjected.

The geology of the other islands may be easily dismissed, for Soay is built of the same Torridonian Sandstones as are encountered in the north of Rhum, whilst Pabbay reveals a complex series of shales such as occur in the south east of Scalpay.

When the diverse geological formations and the equable, if somewhat moist, climate of the islands are taken into account, it is not surprising that they support a rich and varied flora. Including species, segregates in the critical genera and a few hybrids, no fewer than 650 forms are listed below, of which 49 appertain to the genus Rosa, 14 are segregates of *Rubus fruticosus*, 9 belong to the genus Hieracium and 10 to Euphrasia. This compares very favourably with our Raasay list which comprised 603 plants.

It will be noted that a few introduced and naturalised plants are added, but this is in cases in which they force themselves upon one's attention or may be regarded as fully established. In some instances, *Pinus sylvestris*, *Larix europaea*, and *Tilia vulgaris* for example, we have decided after due consideration to ignore them.

Although we heartily deprecate making a fetish of the new county record, we have been able to add no fewer than fifty five species to the lists for V.C. 104. This totalled with the sixty noted in our Flora of Raasay and the five supplied in our "Further Contributions to our Knowledge of the Flora of the Isle of Raasay"* makes a grand total of 120 new county records for V.C. 104.

Moreover, to render the facts more conspicuous, in making these latter calculations no segregates in the greater critical genera have been included.

We must now perform the pleasant duty of making acknowledgements to all of those who have so greatly assisted in securing the success of our enterprise. There is no exaggeration in stating that had it not been for the great kindness of Sir George Bullough, Bart., our final results would scarcely have been worth publishing. Not only did he give permission

*Report Bot. Soc. and Exchange Club, 1937.

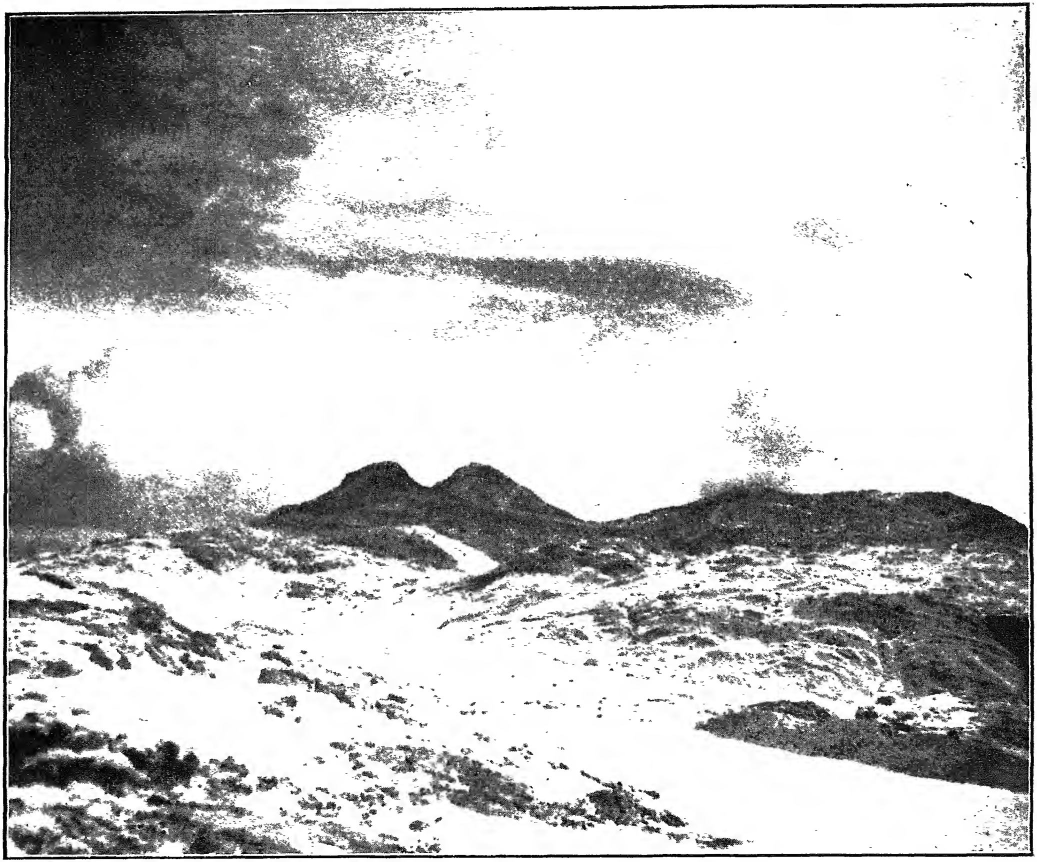


Fig. 3. The Approaches to Hallival, Askival, and Barkeval, Isle of Rhum.

for our lengthy stay on the Isle of Rhum, but, in addition, he facilitated our work by giving us accommodation, and by securing the co-operation of the whole of his people on the island. We can only repeat that everyone with whom we came into contact on Rhum did their very best for us in every conceivable way. Hence to Sir George and all concerned we cannot be too grateful.

Similarly, we have to acknowledge all the kindness displayed, and help so freely given, by Commander and Mrs. MacEwen in connection with our exploration of the Isle of Muck; without them our researches there would have been impossible.

Again, for assistance willingly rendered in a different direction, we have to give our thanks to the authorities of the Royal Botanic Gardens, Kew, and the Royal Botanic Gardens, Edinburgh. Further, our gratitude must be expressed to various authorities for determinations and confirmations in critical groups, Dr. R. W. Butcher for certain Cruciferae, Mr. H. W. Pugsley for the Hieracia and Euphrasiæ, Mr. E. Nelmes for the Carices and Mr. W. Watson for the Rubi.

Finally, every member of the various expeditions realises to the full that, had it not been for generous subsidies from the King's College Research Committee, our investigations would have been impossible, and to that body we offer our sincerest thanks.

(In using the appended list it should be noted that we have used the Eleventh edition of the London Catalogue and that, unless the record is of special importance, the occurrence of a species on Hyskeir is merely indicated by an asterisk* and on Eilean nan Each by a dagger†).

THE LIST OF PLANTS.

RANUNCULACEÆ.

Thalictrum alpinum L. Alpine Meadow Rue.
Only found on Rhum, but there not uncommon on Orval, Barkeval, Hallival etc., at heights of 1,000 feet and over; rarely lower down.

T. dunense Dum. Sand Meadow Rue.
Scattered on the sand dunes at Kilmory and Shamhnan Insir, Rhum, Poll nam Partan and Laig Bay, Eigg, Bagh a Ghallanaich, Muck and on Canna and Sanday.

T. capillare Reich.
On the sea cliffs near Shamhnan Insir, Rhum only; new to V.C. 104.

Anemone nemorosa L. Wood Anemone.
Local, and far from common in grassy places amongst rocks, on Eigg and Soay.

Ranunculus hederaceus L. Ivy-leaved Crowfoot.
Sparingly on all the islands except Soay and Pabbay; perhaps most plentiful near Cleadale, Eigg.

R. sceleratus L. Celery-leaved Crowfoot.
Restricted to the South-East of Canna; new to V.C. 104.

†**R. Flammula** L. Lesser Spearwort.
Common in wet places on every island.

R. Lingua L. Greater Spearwort.
Rare in a loch south of Laig Bay, Eigg; new to V.C. 104.

*†**R. acris** L. Buttercup.
Generally distributed in suitable places on all the islands; var. *pumilus* occurs.

*†**R. repens** L. Creeping Crowfoot.
Present on every island, but more local than the preceding species.

R. bulbosus L. Bulbous-rooted Crowfoot.
Noted on Canna only.

†**R. Ficaria** L. Pilewort.
Found on the whole of the islands except Hyskeir, but local and often confined to rock ledges and shingle.

†**Caltha palustris** L. Marsh Marigold.
Common and well distributed.

Trollius europaeus L. Globeflower.
Collected once in the Orval area of Rhum, but observed freely along streams flowing into Poll nam Partan and Laig Bay, Eigg. The Eigg specimens bore flowers of enormous size.

NYMPHAEACEÆ.

Nymphaea alba L. White Waterlily.
In many lochs on Rhum and Eigg, but missing from some; abundant on Soay.

N. occidentalis L. White Waterlily.
In some of the lochs on Mullach Mor, Rhum, and in several in the north of Soay.

PAPAVERACEÆ.

Papaver Rhoeas L. Poppy.
Very rare in corn in Muck; new to V.C. 104.

P. dubium L. Poppy.
Not rare in corn on Eigg; the usual Hebridean poppy.

FUMARIACEÆ.

Corydalis claviculata DC. Climbing Fumitory.
Common on the roofs of crofts around Camas nan Gall, Soay.

Fumaria capreolata L. Fumitory.
On bank sides around Poll nam Partan, Eigg; new to V.C. 104.

F. Bastardi Bor.
Fields etc. on Eigg and Muck; new to V.C. 104.

F. officinalis L. Common Fumitory.
In fields and waste places in the west of Eigg; not common.

CRUCIFERÆ.

Nasturtium officinale R.Br. Water Cress.
In Eigg in streams near Cleadale, also on Pabbay.

N. sylvestre R.Br.

Fig. 4. The Seaward Cliffs of Bloodstone Hill, Rhum.

On damp ground along the Kinloch Burn as it enters Loch Scresort, Rhum; new to V.C. 104.

Arabis petraea Lam. Rock Cress.
Frequent on the Barkeval, Hallival and Askival massif, Rhum; less common on Orval.

A. hirsuta Scop. Hairy Rock Cress.
Local in dry situations on Rhum, but only noted near the waterfall, Laig, on Eigg.

*†**Cardamine pratensis** L. Cuckoo Flower.
Common on every island, and variable in flower colour, and size.

***C. flexuosa** With.
Common in shady, rocky places.

†**C. hirsuta** L. Hairy Bitter Cress.
Fairly common, but not reported from Sanday or Pabbay.

Draba incana L. Hoary Rock Cress.
Not very common on the Rhum mountains as Fionchra, Barkeval etc.; rare on the cliffs between Beinn Bhuidhe and Cleadale, Eigg.

*†**Cochlearia officinalis** L. Scurvy Grass.
Common on all the islands, even Coralag, on the coasts.

C. alpina Wats. Alpine Scurvy Grass.
Sparingly on Barkeval, and on wet cliffs on the north side of Fionchra, Rhum.

*†**C. danica** L.
Common in several stations on Muck, Eilean nan Each and Hyskeir, rarer on Eigg; new to V.C. 104.

C. scotica Dr. Northern Scurvy Grass.
Not at all rare; shores of every island.

C. anglica L.
Scarce on Canna Harbour, Canna; new to V.C. 104.

***Sisymbrium Thalianum** Gay. Thale Cress.
Rare and quite local; rock debris, Fionchra, and Kilmory and Shamhnan Insir, Rhum; oddly enough also on Hyskeir.

S. officinalis Scop.
Uncommon, Eigg and Sanday in its typical form; var. *leiocarpum* DC. Kinloch, Rhum.

Erysimum orientale Mill.
A casual around the buildings, Kinloch, Rhum.

Brassica arvensis L. Charlock.
As a weed of cultivation, Eigg, Canna, Sanday, Muck and Pabbay.

Capsella Bursa pastoris Med. Shepherd's Purse.
Common enough on the larger islands on disturbed ground; but not seen on Soay.

Thlaspi calaminare Lej. & Court. Alpine Penny Cress.
A very unexpected find, giving the species a remarkable extension to its known range; found inland on the drier cliffs of Fionchra, and on the seaward side of Bloodstone Hill, Rhum. New to Scotland.

Teesdalia Lepidium DC.
A small group of plants of this plant, new to Britain, was found on sandy ground near Laig Bay, Eigg.

Cakile maritima Scop. Sea Rocket.
Rare in sand on Laig Bay, Eigg, and once on the shores of Loch Scresort, Rhum.

Raphanus Raphanistrum L.
In fields on Eigg and Sanday.

VIOLACEÆ.

Viola palustris L. Marsh Violet.
Common in damp places, Eigg, Rhum, Muck, Soay and Pabbay.

V. silvestris Lam. Violet.
On Rhum, Muck and Eigg, not common.

†**V. Riviniana** Reich.
Common, and distinctly variable on all the islands, some of the rock forms approaching *V. silvestris.*

V. canina L. Dog Violet.
Noted on Rhum, Eigg and Muck, but never plentiful.

V. Lloydi Jord. Pansy.
In the cornfields around Cleadale, Eigg; new to V.C. 104.

V. obtusifolia Jord.
Drawn up forms of this occurred in the corn on Eigg and Pabbay.

V. ruralis Jord.
In a field on Muck in the centre of the island; new to V.C. 104.

V. Curtisii Forster.
On the Eigg sand-dunes, generally somewhat local; new to V.C. 104.

POLYGALACEÆ.

†**Polygala vulgaris** L. Milkwort.
Appears not to be uncommon on all the islands except Soay; some forms approach the next species.

P. dubia Bellynck.
Frequent and also variable.

†**P. serpyllacea** Weihe.
Widely distributed on the islands, but we failed to find it on Canna, Sanday and Soay.

CARYOPHYLLACEÆ.

*†**Silene maritima** With. Sea Campion.
On cliffs and shingle on all the islands; often plentiful, except on Rhum, where it is local and western. On Hyskeir it occasionally forms the major portion of the sward.

S. acaulis L. Moss Campion.
Common on Rhum, both on the mountains like Barkeval, Bloodstone Hill etc., and on the sea cliffs, and in ravines leading from them between Bloodstone Hill and Harris; on Eigg plentiful on Sgor an Fharaidh, also on sea cliffs on Canna.

Lychnis dioica Mill. Red Campion.
Very rare and local, except on Canna, where it abounds in one of the woods; in Rhum, found on the sea cliffs of Bloodstone Hill, in Eigg on rocks near the waterfall, Laig Bay, in Muck on a cliff near Ard nan Uan, in Soay on a cliff just north of Beinn Bhreac, and more plentifully on the cliffs in the east of Pabbay.

*†**L. Flos-cuculi** L. Ragged Robin.
Plentiful everywhere, even on Hyskeir, where it may be found growing with such associates as *Carex arenaria* etc.

Cerastium tetrandrum Curt. Mouse-ear Chickweed.
Not rare in sandy places near the sea on the larger islands.

C. semidecandrum L.
Sparingly at Kilmory, Rhum, and on Sanday; new to V.C. 104.

*†**C. viscosum** L. Broad-leaved Mouse-ear Chickweed.
Common enough, especially on Eigg.

*†**C. vulgatum** L. Mouse-ear Chickweed.
Common and widespread.

*†**Stellaria media** Vill. Chickweed.
Abundant wherever cultivation exists.

S. neglecta Weihe.
Around the Harbour, Eigg, rare, a new county record.

S. Holostea L. Stitchwort.
On cliffs near Port na Maol, Muck, and around Poll nam Partan, Eigg.

S. graminea L. Lesser Stitchwort.
In a ride in a wood near Kinloch, Rhum, and in similar places in the south east of Eigg.

S. uliginosa Murray. Bog Stitchwort.
Generally distributed in watery places on the bigger islands.

Arenaria trinervia L. Three nerved Sandwort.
Not at all rare in the woods near the Harbour, Eigg, very rare in those at the head of Loch Scresort, Rhum.

***A. serpyllifolia** L. Thyme-leaved Sandwort.
Fairly well spread in sandy places in most of the islands, including Hyskeir, but not Soay and Pabbay. The var. *viscidula* was noted on Eigg.

A. norvegica Gunn.
Another important discovery made on Rhum, where the plant occurred in some quantity on a bare rocky plateau in the south; a new county record and a great extension of range.

A. peploides L. Sea Purslane.
Local and far from frequent; Laig Bay, Eigg, Sanday, and on the northern coasts of Muck.

A. sedoides Dr.
On the Barkeval, Hallival, Askival group of mountains of Rhum; quite common in the same habitats as Lightfoot made the first British record in 1777.

†**Sagina maritima** G. Don.
Very rare, on Eilean nan Each only; new to V.C. 104.

*†**S. procumbens** L. Pearlwort.
Very common on all the islands.

S. apetala Ard.
Occurs sparingly, and seems to be confined to the Isle of Rhum; a new county record.

S. subulata Presl.
Found on Rhum, Eigg, Sanday and Muck, ascending to 2,000 feet on Rhum and to the highest point on Muck.

S. nodosa Fenz. Knotted Pearlwort.
Scattered, but not really common, on bare, heathy places in Rhum and Sanday.

Spergula sativa Boenn. Corn Spurrey.
Abundant in cultivated places on all the islands except Rhum, where it is necessarily rare.

Spergularia marginata Kittel. Sea Spurrey.
Around Loch Scresort, Rhum, and Canna Harbour, Canna and Sanday, the Rhum plant being var. *angustata* Clav.

Polycarpon tetraphyllum L.
A single plant found growing in a rock crevice along the Kinloch Burn, Rhum; a new county record.

PORTULACEÆ.

†**Montia fontana** L. Water Blinks.
More or less plentiful in the form of the var. *lamprosperma* Cham. on most islands.

HYPERICACEÆ.

Hypericum Androsaemum L. Tutsan.
Here and there on the sea cliffs, chiefly on sandstones on Rhum, Eigg, Muck, Soay and Pabbay.

H. perforatum L. St. John's Wort.
Rare on the lower stretches of Allt Slugan a Choilich, Rhum; a new county record.

H. tetrapterum Fr.
Not common in the west of Eigg, but locally fairly plentiful on Muck.

H. humifusum L. Creeping St. John's Wort.
Very rare; dry banks near Port Mor, Muck, and Cleadale, Eigg.

H. pulchrum L. Beautiful St. John's Wort.
Abundant almost everywhere on moorlands, stream-sides etc., but failing on Hyskeir. The var. *procumbens* Rostrup also occurs.

H. elodes L.
Has been reported from Canna.

LINACEÆ.

†**Linum catharticum** L. Purging Flax.
Common on bare moorands, banks, sand-dunes etc., on nearly all the islands, even on Coralag.

GERANIACEÆ.

Geranium pratense L. Meadow Crane's-bill.
Very rare on path edges in the woods, Kinloch, Rhum; new to V.C. 104.

G. molle L. Dove's Foot Crane's-bill.
On cultivated areas in Rhum, Eigg, Muck and Soay.

G. dissectum L. Cut-leaved Crane's-bill.
Occasionally with the preceding, but apparently absent from Muck.

G. Robertianum L. Herb Robert.
On every island except Hyskeir in the form of a shingle plant; never really common.

Erodium cicutarium L'Herit. Stork's-bill.
On sand-dunes, Kilmory Bay and Harris, Rhum, and Poll nam Partan, and Laig Bay, Eigg.

Oxalis Acetosella L. Wood Sorrel.
Always very rare, and local, and often as a plant of rock ledges, but found on all the larger islands.

AQUIFOLIACEÆ.

Ilex Aquifolium L. Holly.
Observed very rarely on cliff ledges, sometimes inland, but generally on the coasts of Rhum and Eigg. Judging from some of its habitats, its distribution has been much wider in former times.

ACERACEÆ.

Acer Pseudoplatanus L. Sycamore.
Naturalised on Rhum, Eigg and Canna.

LEGUMINOSÆ.

Ulex europaeus L. Whin, Gorse.
Low down on the burn running from Barkeval, and on the Kilmory Road, Rhum, also on Canna, Sanday and Pabbay; always rare.

Cytisus scoparius Link. Broom.
In and near the woodlands, Loch Scresort, Rhum, and on Canna.

Medicago lupulina L. Non-such.
Very rare, Canna and Muck near, or on, cultivated ground.

*†**Trifolium pratense** L. Common Clover.
Common everywhere, in all suitable places; with var. *maritimum* on Hyskeir (where it is the only clover) and elsewhere.

†**T. medium** L. Zig-zag Clover.
Locally not rare near the sea, not however observed on Pabbay.

T. repens L. Dutch Clover.
Likewise widely distributed on the islands.

T. procumbens L. Hop Trefoil.
Never common; Eigg, Canna, Muck, Soay.

T. dubium Sibth.
Not uncommon locally; Rhum, Eigg, Sanday and Muck.

†**Anthyllis Vulneraria** L. Kidney Vetch.
Abundant on sand-dunes, pastures, cliffs etc. except on Soay: reaching 1,500 feet on Barkeval, Rhum.

*†**Lotus corniculatus** L. Bird's Foot Trefoil.
Very common on every island, with some examples approaching var. *hirsutus* Rouy.

L. uliginosus Schkuhr.
Rather rare; Rhum, Eigg, Muck and Pabbay; the var. *glabriuscula* Bab. turned up in Kinloch Woods, Rhum.

Vicia hirsuta Gray. Hairy Tare.
Quite scarce; Eigg, Canna and Pabbay.

V. Cracca L. Blue Vetch.
Not at all rare on all the larger islands.

V. Orobus DC. Bitter Vetch.
On sea cliffs on Shamhnan Insir and in a gorge at 1,000 feet on Barkeval, Rhum, on cliffs on Canna and on the seaward side of the Maol, Muck.

V. sylvatica L. Wood Vetch.
Rare on cliffs between Papadil and Ruinsival, and on Camas na h-Acha, Rhum, as well as in the west of Canna.

V. sepium L. Bush Vetch.
Never very common, but on most of the islands; ascends to 1,250 feet on Fionchra.

***V. angustifolia** L.
Rare and only on Canna and Hyskeir; the occurrence on the Hyskeir reef, amongst grass and far from the lighthouse, seems remarkable.

V. sativa L. Tare.
Only on Canna.

Lathyrus pratensis L. Meadow Vetchling.
Common in grassy places generally when rather damp.

L. montanus Bernh. Tuberous-rooted Bitter Vetch.
Also of free occurrence in grassy places, but of drier proclivities; the var. *tenuifolius* Dr. was noted on Rhum.

ROSACEÆ.

Prunus spinosa L. Blackthorn.
Common between Cleadale and the Post Office on Eigg, scarce on rocks above Port Mor, Muck and on Soay Harbour, Soay.

P. avium L. Gean.
In woods, Canna.

†**Spiraea Ulmaria** L. Meadow Sweet.
On marshy ground, chiefly in the lowlands; everywhere save Hyskeir.

Rubus idaeus L. Raspberry.
Never common except in Kinloch Woods, Rhum, but on nearly all the islands.

R. incurvatus Bab. Bramble.
On Rudha na Roinne, Kinloch, Rhum, Eigg and Sanday.

R. nemoralis P.J.Muell.
On Soay only.

R. dumnoniensis Bab.
Around Kinloch, Rhum.

R. polyanthemus Lindeb.
Eigg and Muck.

R. villicaulis Koehl.
On Eigg.

R. Selmeri Lindeb.
Also on Eigg and Muck.

R. rhombifolius Whe.
Only recorded from Pabbay.

R. gratus Focke.
On Eigg and Canna.

R. Sprengelii Whe.
In Kinloch Woods, Rhum.

R. mucronifer Sudre.
On Soay.

R. lasiothyrsis Sudre.
Likewise on Soay only.

R. radula Whe.
Eigg and Canna.

R. corylifolius Sm.
Eigg, Soay and Canna.

R. saxatilis L. Stone Bramble.
High on the mountains, Barkeval etc., Rhum, cliffs on Eigg, Canna and Soay.

Dryas octopetala L. Mountains Avens.
On the cliffs above Cleadale, Eigg and fairly low on the limestone just west of Kilmory, Rhum; not found on the mountains of the latter island.

Geum urbanum L. Wood Avens.
Rare in the woods running down to Poll nam Partan, Eigg and also in woods on Canna; further islands for the species in V.C. 104.

G. rivale L. Water Avens.
In the major islands in various types of habitat, but not plentiful; only on the cliffs on the north face of Fionchra on Rhum.

G. intermedium Ehrh. (= **G. urbanum** x **G. rivale**).
Where the two preceding species clash on Poll nam Partan, Eigg.

Fragaria vesca L. Strawberry.
Widespread, but local on rock ledges and ravines on every island except Pabbay.

Potentilla sterilis Garcke. Barren Strawberry.
Rare on the area near the Harbour, Eigg.

*†**P. erecta** Hampe. Tormentil.
Everywhere common; its occurrence on peat on the Hyskeir reef points to the fairly recent subsidence of that islet.

P. procumbens Sibth.
Very scarce on Canna; new to V.C. 104.

*†**P. Anserina** L. Silver-weed.
Often common in waste places and on shingle.

P. palustre Scop.
Found on all the bigger islands except Eigg, and occasionally very plentiful as on the alluvial flats near Kilmory, Rhum.

Alchemilla arvensis Scop. Parsley Piert.
On waste places on Rhum, Eigg, Canna and Muck; rare.

A. pratensis Schmidt. Lady's Mantle.
Rare near Kinloch, Rhum and Sanday; new to V.C. 104.

A. alpestris Schmidt.
Scattered on Rhum, Canna and Muck.

A. minor Huds.
Sparingly near Laig Bay, Eigg with the var. *filicaulis* Buser on Fionchra, Rhum; new to V.C. 104.

A. alpina L. Alpine Lady's Mantle.
Common enough on many of the Rhum mountains; also sparingly on Canna.

Agrimonia odorata Mill. Agrimony.
On wood edges from the Harbour to Poll nam Partan, Eigg; the only previous record for V.C. 104 was our own from Raasay.

Rosa canina L. Agg. Dog-rose.

Lutetianae group.

(a) Var. **lutetiana** Baker. Rare; Rhum, Canna, Soay.
 (1) f. **lasiostylis** Loch Scresort, Rhum.
(b) Var. **sphaerica** Dum. Rhum only.
(c) Var. **flexibilis** Déségl. Eigg.
(d) Var. **oxyphylla** Rip. Kinloch, Rhum.

Transitoriae group.

(e) Var. **spuria** Pug. Cliffs, Rhum.
(f) Var. **insignis** B. & C. Camas nan Gall, Soay.
(g) Var. **rhynchocarpa** Rip. Kinloch, Rhum.

Dumales group.

(h) Var. **dumalis** Bech. Rhum, Canna, Soay.
 (1) f. **viridicata** Pug. Sanday.
 (2) f. **cladoleia** Rip. Rhum.
(i) Var. **biserrata** Mer. Canna.
(j) Var. **Carioti** Chab. Low cliffs, Kilmory, Rhum.
(k) Var. **recognita** Rouy. Cliffs on Pabbay.
(l) Var. **fraxinoides** H. Br. Pabbay.

Andegavenses group.

(m) Var. **vertillacantha** Mer. Eigg.

R. dumetorum Thuill. Agg.

Pubescentes group.

(a) Var. **urbica** (Lem.) W. Dod. Rare, two bushes only, near Kinloch, Rhum.
(b) Var. **hemitricha** (Rip). W. Dod. On Sanday. The occurrence of these two *dumetorum* forms seems remarkable in view of their absence elsewhere in the Hebrides.

R. glaucophylla Winch. Agg.

(a) Var. **Reuteri** (God.) H.-Harr. Somewhat rare on Rhum, Sanday, Canna and Soay.
  (1) f. **transiens** (Gren.) H.-Harr. Rhum.
(b) Var. **subcristata** (Baker) H.-Harr. Not uncommon save on Pabbay.
  (1) f. **adenophora** (Gren.) H.-Harr. Rhum and Eigg.
(c) Var. **stephanocarpa** Déségl. et Rip. Pliasgaig, Rhum.

Subcaninae group.

(d) Var. **subcanina** (Chr.) H.-Harr. Rhum and Eigg.
(e) Var. **denticulata** (R.Kell.) H.-Harr. Rhum.
(f) Var. **pseudo-Haberiana** (R.Kell.) H.-Harr. Eigg.
(g) Var. **macrocala** (Schnetz.) H.-Harr. Pabbay cliffs.
(h) Var. **ungulata** (Schnetz.) H.-Harr. Soay.
(i) Var. **Bartlettiana** H.-Harr. Near Rudha na Roinne, Rhum.

R. caesia Sm. Agg.

(a) Var. **frutetorum** (Chr.) H.-Harr. Pabbay only.

R. tomentella Lem.

(a) Var. **sclerophylla** Sch. The first specimens noted for Scotland were collected on Eigg in 1937.

R. mollis Sm. Agg.

(a) Var. **typica** W. Dod. On low cliffs, Kilmory, Rhum.

R. Sherardi Dav. Agg.

(a) Var. **typica** W.-Dod. Scattered on Rhum, Eigg and Pabbay.
  (1) f. **submollis** Ley. Rhum, Soay, Pabbay.
  (2) f. **pseudomollis** Ley. Rhum, Eigg, Muck, Canna and Soay.
  (3) f. **uncinata** Lees. Rare on the same islands but not seen on Eigg.
(b) Var. **omissa** (Déségl.) H.-Harr. Eigg, Rhum, Muck and Soay.
(c) Var. **Woodsiana** (Groves) H.-Harr. Pabbay.
(d) Var. **suberecta** (Ley) H.-Harr. Eigg.

(e) Var. **glabrata** (Ley) H.-Harr. Pabbay.

R. spinosissima L.

(a) Var. **typica** W.-Dod. Rhum, Eigg, Canna, Muck and Soay.
(b) Var. **pimpinellifolia** L. With the preceding.
(c) Var. **inermis** DC. Canna.

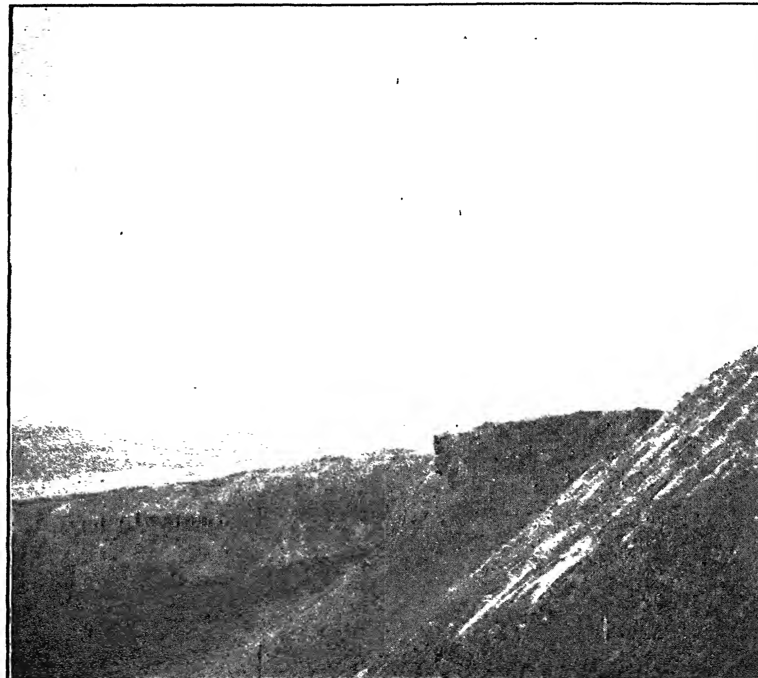


Fig. 5. The Cliffs of Fionchra with Skye in the Background.

(d) Var. **Ripartii** Déségl. Eigg.
(e) Var. **rosea** Koch. Muck and Eilean nan Each; some forms shade into a deep buff-orange.
(f) Var. **turbinata** Lindl. Papadil, Rhum.

R. spinosissima x **R. Sherardi.**
On Rhum, Eigg and Soay. In the second island the two reciprocal hybrids occur, and, as their chromosome complements would lead one to anticipate, they are quite distinct. The form **R. Sherardi** male x **R. spinosissima** female is here named x **R. Boltoni.**

R. rubiginosa L. Agg.
(a) Var. **typica** W.-Dod. Only found on Rhum in a little ravine on the north eastern slope of Mullach Mor.

Sorbus Aucuparia L. Mountain Ash.
Thinly scattered in rocky and somewhat sheltered situations on the larger islands; more abundant on the inaccessible top of the small island of Stac nam Faoilleann off the east of Rhum, where it fruits freely.

S. Aria Crantz. White Beam.
In Kinloch Woods, Rhum and, no doubt, introduced.

Crataegus Oxyacantha L. Hawthorn.
Not common, Papadil, Rhum; new to V.C. 104.

C. monogyna Jacq. Hawthorn.
On Rhum, Eigg, Muck and Pabbay; if it is an introduction on Rhum that event occurred over 100 years ago for the plant occurs at Shamhnan Insir and carries the Psyllid *Psylla pergrina.*

Cotoneaster Simonsii Baker. Cotoneaster.
Naturalised on Rhum and self sown on cliffs on Pliasgaig Bay and on the slopes of Hallival.

SAXIFRAGACEÆ.

Saxifraga oppositifolia L. Purple Saxifrage.
Common on the mountains of Rhum, descending almost to 100 feet just south of Bloodstone Hill in the west of the island, and also in Dibidil were it is associated with *Ajuga pyramidalis* in the waterfall ravine.

S. nivalis L.
Very rare; only on Rhum on the dripping rocks on the northern slopes of Fionchra.

S. stellaris L. Starry Saxifrage.
In wet places, often amongst moss, but sometimes in rock cracks in the mountains; confined to Rhum where it descends nearly to sea level.

S. Aizoides L. Yellow Saxifrage.
At sea level in a ravine to the north of Kilmory Bay, and on the limestone of the same area, Rhum, also on the cliffs above the Singing Sands, Eigg.

S. hypnoides L. Mossy Saxifrage.
Scattered over the mountains of Rhum, often on rocks; some times also associated with *Chrysosplenium oppositifolium* as on Ard Nev, on cliffs on Eigg and Canna.

Chrysosplenium oppositifolium L.
Opposite-leaved Golden Saxifrage.
Sparingly on sea cliffs and on rocky gorges leading to the sea on Rhum, Eigg, Canna, Muck and Pabbay; occasionally above 1,000 feet on the mountains of Rhum as on Orval and Ard Nev.

Parnassia palustris L. Grass of Parnassus.
Not common, and chiefly in sandy areas near the sea; Rhum, Eigg, Canna, Sanday and Muck.

CRASSULACEÆ.

Sedum roseum Scop. Roseroot.
On sea cliffs on all the larger islands as well as in mountain gorges on Rhum.

*†**S. anglicum** Huds. English Stonecrop.
On rocks on every island, Coralag included.

S. acre L. Biting Stonecrop.
Rare on sand dunes on all the major islands except Canna and Soay.

DROSERACEÆ.

Drosera rotundifolia L. Round-leaved Sundew.
Also on all the more important islands.

D. anglica Huds. Long-leaved Sundew.
On the same islands except Muck.
The hybrid **D. obovata** Mert. & Koch occurs not uncommonly where the two species just named grow together.

D. longifolia L.
Very plentiful everywhere along the valley of the Kinloch Burn, Rhum, on the moorlands; also more rarely on Eigg, between the Sgurr and the Post Office.

HALORAGACEÆ.

Myriophyllum spicatum L. Water Milfoil.
Sparingly on Muck; second record for the county.

M. alternifolium DC. Water Milfoil.
Rather common on Rhum, Muck and Soay.

Callitriche stagnalis Scop. Starwort.
Common in wet places, streams etc. on all the islands.

***C. intermedia** Hoffm. Starwort.
Not rare in the lochs etc. of Rhum, Eigg, Muck and Soay.

LYTHRACEÆ.

Lythrum Salicaria L. Purple Loosestrife.
In a marshy field north of Kinloch, Rhum and on Eigg, a second and third island respectively for the species in the vice county.

ONAGRACEÆ.

Epilobium angustifolium L. Rosebay Willow Herb.
On the seaward cliffs of Bloodstone Hill, Rhum and on Pabbay; as usual in a form very unlike the usual English plant.

E. parviflorum Schreb.
On stream sides etc., Rhum, Eigg and Canna.

E. montanum L. Willow Herb.
Common on the bigger islands.

E. tetragonum L.
Pabbay only; this is a third island for the vice county, and the locality links up with the Raasay, Scalpay stations.

E. obscurum Schreb.
Uncommon on Rhum, Eigg, Canna, Muck and Pabbay.
***E. palustre** L. Marsh Willow Herb.
Noted on all the large islands as well as on Hyskeir.
E. alsinefolium Vill.
On a stream leading from An Cruachan, Eigg.
Circaea lutetiana L. Enchanter's Nightshade.
Rare on Eigg in the woodlands in the east, also around Soay Harbour, Soay.
C. alpina L. Alpine Enchanter's Nightshade.
On the cliffs above Cleadale, Eigg.

UMBELLIFERÆ.

†**Hydrocotyle vulgaris** L. Marsh Penny Wort.
Common generally.
Sanicula europaea L. Wood Sanicle.
Rare and very local; ravine near Creag na h'Iolaire, Rhum, near Laig, Eigg, cliff ledge, Port Mor, Muck, birch copses, Soay.
Conium maculatum L. Hemlock.
Rare; stream side on the south east of Eigg.
Aegopodium Podagraria L. Goutweed.
Not common in limited areas on the islands.
Conopodium majus Loret. Earthnut.
Far from rare in grassy places on Eigg and Muck.
Myrrhis Odorata Scop. Sweet Cicely.
Occasional on Eigg and Canna; a new county record.
Chaerophyllum temulum L.
Also on the same islands; and likewise a county record.
***Anthriscus sylvestris** Hoffm.
On the bigger islands except Canna.
Oenanthe Lachenalii Gmel.
In a small salt marsh near Harris, Rhum, very rare; new to V.C. 104.
Oe. crocata L. Water Dropwort.
Found in wet places, on the sea shore, etc. on most of the islands.
†**Ligusticum scoticum** L. Lovage.
On sea cliffs on the whole of the larger islands except Muck; abundant
*†**Angelica sylvestris** L. Angelica.
Common in damp places on every island.
***Heracleum Sphondylium** L. Cow Parsnip.
Thinly distributed, but commoner than on Raasay and its neighbours.
*†**Daucus Carota** L. Wild Carrot.
Not seen on Soay; common enough elsewhere.
Caucalis Anthriscus Huds. Hedge Parsley.
Occasional on Eigg and Muck.

ARALIACEÆ.

Hedera Helix L. Ivy.
Not rare on sea and other cliffs on all the islands; occasional on trees on Eigg.

CAPRIFOLIACEÆ.

Sambucus nigra L. Elder.
In woods, copses etc.; all islands.

†**Lonicera Periclymenum** L. Honeysuckle.
Well spread nearly everywhere, chiefly on rocks, cliffs, etc.

RUBIACEÆ.

Galium boreale L.
On rocks near the waterfall, Laig Bay, and on the cliffs above Cleadale, Eigg.

†**G. verum** L. Lady's Bedstraw.
Plentiful on the islands, even on Coralag and Eilean nan Each; a contrast to its absence on the islands north of Skye.

†**G. saxatile** L. Heath Bedstraw.
Abundant and general on heaths.

G. palustre L. Marsh Bedstraw.
Widely distributed and common.

*†**G. Aparine** L. Cleavers.
Nearly always a shingle plant in these islands, and in such situations not rare.

G. pumilum Murray.
Scarce on the Cleadale cliffs, Eigg.

Asperula odorata L. Woodruff.
In woods bordering Poll nam Partan, Eigg only.

Sherardia arvensis L. Field Madder.
Casually on Canna.

VALERIANACEÆ.

Valeriana dioica L. Small Valerian.
Very local in marshes on Eigg; a new county record.

V. officinalis L. Great Valerian.
Scattered on Rhum, Eigg, Canna and Pabbay; generally on sea cliffs and very rare.

Valerianella olitoria Poll. Lambs' Lettuce.
Plentiful around Poll nam Partan, Eigg, not seen elsewhere.

DIPSACEÆ.

†**Scabiosa Succisa** L. Devils' Bit Scabious.
Abundant nearly everywhere.

COMPOSITÆ.

Eupatorium cannabinum L. Hemp Agrimony.
In damp places on the cliffs above the Singing Sands, Eigg.

†**Solidago Virgaurea** L. Golden Rod.
Common in rocky places; many of the mountain forms are to be referred to var. *cambrica* Huds..

*†**Bellis perennis** L. Daisy.
Common enough everywhere.

Filago gallica L. Narrow-leaved Cudweed.
Along a sandy path-side south of Kilmory, Rhum, very variable in size; new to Scotland and a very remarkable find.

Antennaria dioica Gaertn.
Well distributed on all the islands from sea level on Muck, to over 2,000 feet on Rhum; the var. *hyperborea* occurs on Barkeval.

Gnaphalium uliginosum L.
Sparsely distributed on Eigg.

G. sylvaticum L.
On the coast near Glen Sheliesder, Rhum, Eigg and Soay.

Inula Helenium L. Elecampane.
Rhum and Canna; no doubt introduced.

***Achillea Millefolium** L. Yarrow.
Common in grassy places.

A. Ptarmica L. Sneezewort.
Common in wet grassy places, but not on Muck.

Anthemis Cotula L. Stinking Mayweed.
Waste places on Eigg and Canna; new to V.C. 104.

Chrysanthemum segetum L. Corn Marigold.
Common enough in corn on Eigg, Canna, Muck and Pabbay.

C. Leucanthemum L. Ox-eye Daisy.
Rare and local on Rhum, Eigg, Canna and Muck.

***†Matricaria inodora** L. Mayweed.
Of free occurrence in cultivated ground; form *maritima* L. on Hyskeir and the west of Rhum.

M. suaveolens Buchenan.
Waste places, fairly general.

Tanacetum vulgare L. Tansy.
Scarce on Eigg, Muck and Pabbay.

Artemisia vulgaris L. Mugwort.
Waste places Eigg, Canna and Sanday.

Tussilago Farfara L. Coltsfoot.
Only in one locality on the N.W. coast of Rhum; sparingly on other islands.

Petasites ovatus Hill. Butterbur.
Rare, streamsides on Eigg and Muck.

***Senecio vulgaris** L. Groundsel.
Common enough on cultivated and waste ground.

***†S. Jacobaea** L. Ragwort.
On all the islands; chiefly on sandy places, dunes, etc.

†S. aquaticus Hill. Marsh Ragwort.
Common in wet ground but not ascending far.

Carlina vulgaris L. Carline Thistle.
Rather rare; cliffs on Canna and Eigg, Glen Duian and Papadil, Rhum.

Arctium majus Bernh. Burdock.
Waste ground; Rhum, Eigg, Canna, Sanday; new to V.C. 104.

***A. nemorosum** Lej.
Sparingly Rhum, Eigg, Muck and Hyskeir.

A. minus Bernh.
Rare on Eigg and Pabbay.

***†Cnicus lanceolatus** Willd. Spear Thistle.
Common in grassy places.

***†C. palustris** Willd. Marsh Thistle.
Common in wet places everywhere.

C. arvensis Hoffm.
Common usually, but rare on Rhum.

C. heterophyllus L. Melancholy Thistle.
On the cliffs above Cleadale, Eigg, common; rare in the northern half of Soay.

Saussurea alpina DC. Alpine Sawwort.
Quite rare; only seen on Hallival and Barkeval, Rhum.

Centaurea obscura Jord. Knapweed.

***C. nemoralis** Jordan.
Both occur, but we have not determined their exact distribution; *C. nemoralis* appears to be the rarer.

Lapsana communis L. Nipplewort.
Not common, but collected on Rhum, Eigg, Canna, Soay and Pabbay; on Rhum only near Papadil.

***Crepis capillaris** Wallr. Smooth Hawksbeard.
Occurs everywhere.

C. mollis Aschers.
Rare on Rhum; an interesting new county record.

C. paludosa Moench.
In swampy places on Muck.

Hieracium iricum Fr. Hawkweed.
Rare on Eigg.

H. anglicum Fr.
The type and var. *acutifolium* backh. were not uncommon on Fionchra, Rhum, but flowers are scarce as they are eaten off by deer; var. *longibracteatum* F.J.H. occurs on Eigg.

H. caledonicum F.J.H.
On the Sgurr of Eigg and seacliffs, Rhum, also on Pabbay.

H. argenteum Fr.
On the cliffs, Pliasgaig, Rhum.

H. Sommerfeltii Lindb.
An Maol, Muck.

H. Shoolbredi E. S. Marshall.
In Dibidil, Rhum,

H. euprepis F.J.H. var. **glabratum** Linton.
Isle of Eigg, cliffs above Laig.

†H. crocatum Fr.
Muck and Eigg.

H. Pilosella L. Mouse-ear Hawkweed.
Frequent, grassy banks, dunes etc.

***†Hypochoeris radicata** L. Cat's Ear.
Quite common generally.

Leontodon taraxacoides Lacaita. Hawkbit.
Not common, Eigg, Canna, Sanday only; new to V.C. 104.

L. hispidum L. Hawkbit.
Fairly common in grassy places Rhum, Eigg, Canna and Coralag; confirms the species for V.C. 104.

L. autumnale L.
Frequent on Rhum, Eigg, Sanday and Muck.

***†Taraxacum vulgare** Schr. Dandelion.
Common in grassy places.

T. laevigatum DC.
Dunes on Rhum, Eigg, Sanday and Muck.

T. paludosum Schlech.
On Rhum, Eigg and Canna.

T. spectabile Dahlst.
Rhum, Eigg, Muck, Pabbay.

***Sonchus oleraceus** L. Sow Thistle.
Occasionally on the bulk of the islands, especially near the sea.

***S. asper** Hill. Rough Sow Thistle.
Much the same distribution as its ally.

S. arvensis L. Corn Sow Thistle.
Rather rare; Rhum, Eigg, Canna, Pabbay.

CAMPANULACEÆ.

Lobelia Dortmanna L. Water Lobelia.
Common in most of the lochs, Rhum, Eigg and Soay.

Campanula rotundifolia L. Harebell.
Not common; in western Eigg, Muck and Soay; var. *lancifolia* on Eigg.

C. rapunculoides L. Creeping Bellflower.
Behind the dunes, Laig Bay, Eigg.

VACCINIACEÆ.

Vaccinium Vitis-Idaea L. Cowberry.
Occasionally on rocky slopes on the Rhum mountains.

V. Myrtillus L. Blaeberry.
Not very plentiful on the moorlands; Rhum, Eigg, Canna, Soay and Pabbay.

ERICACEÆ.

Arctostaphyllos Uva-ursi Spreng. Bearberry.
Very rare and local; in one or two places on the western slopes of Mullach Mor, Rhum, above Soay Harbour, Soay, and on Eigg.

†**Calluna vulgaris** L. Heather.
Very abundant on nearly every island; it should be noted that it has just become extinct on Hyskeir.

Erica Tetralix L. Cross-leaved Heath.
Very common in wet peaty habitats.

E. cinerea L. Fine-leaved Heath.
Very plentiful in drier spots than its congener.

Pyrola minor L. Lesser Winter-green.
Exceedingly rare; only noted in a sheltered gorge leading from Hallival, Rhum.

P. media Sev. Winter-green.
Common amongst grass in one station just west of Poll nam Partan, Eigg.

Rhododendron ponticum L.
Naturalised in, and near, the Kinloch Woods, Rhum.

PLUMBAGINACEÆ.

*†**Armeria maritima** Willd. Sea Pink.
Common on rocky coasts in all the islands, and occasionally in the Rhum mountains.

PRIMULACEÆ.

†**Primula vulgaris** L. Primrose.
Abundant in all suitable places.

Lysimachia nemorum L. Wood Pimpernel.
Very rare and local; occasionally in gorges inland, but more often on the coast on sheltered ledges.

***Glaux maritima** L. Sea Milkwort.
Here and there on the coasts of all the islands.

†**Anagallis arvensis** L. Scarlet Pimpernel.
Not common; Eigg, Canna and Muck.

A. tenella Murr. Bog Pimpernel.
Frequent in the lower lying moist places; ascends to 1,000 feet on Eigg.

Centunculus minimus L. Chaffweed.
Rather local, but common, in bare damp places between Kilmory and Kinloch, Rhum, and on Soay Harbour.

OLEACEÆ.

Fraxinus excelsior L. Ash.
Rare on Rhum, Eigg, Canna and Muck; possibly only native on Eigg in a ravine near Laig.

GENTIANACEÆ.

***Erythraea Centaurium** Pers. Centaury.
Not plentiful and also local; Harris on Rhum, Sanday, Canna, Eigg, Muck, Coralag and Hyskeir.

Gentiana baltica Murb.
Rare; grassy places near the sea, Harris and Shamhnan Insir, Rhum; new for V.C. 104.

G. campestris L. Field Gentian.
Frequent in grassy places on most of the islands including Coralag.

Menyanthes trifoliata L. Bog Bean.
Common in peaty pools and lochs on nearly all the islands; *not* seen on Canna.

BORAGINACEÆ.

Symphytum officinale L. Comfrey.
Not common; Canna; a new county record.

Lycopsis arvensis L.
Rather rare on Eigg and Canna.

Mertensia maritima Gray. Oyster Plant.
Only found by us on Sanday, and there exceedingly rare on shingly shores; also reported from Eigg.

†**Myosotis cespitosa** Schultz. Forget-me-not.
Local in wet places on the various isles.

M. palustris Hill.
Rare near Kinloch, Rhum, Sanday, and near Cleadale, Eigg.

M. repens G. & D. Don.
Restricted to Eigg and Muck.

M. collina Hoffm.
Eigg and Soay.

M. arvensis Hill. Field Scorpion Grass.
Cultivated and waste ground on all the islands except Rhum and Canna.

M. versicolor Sm.
Of fairly common occurrence on dry sandy ground on all the major islands.

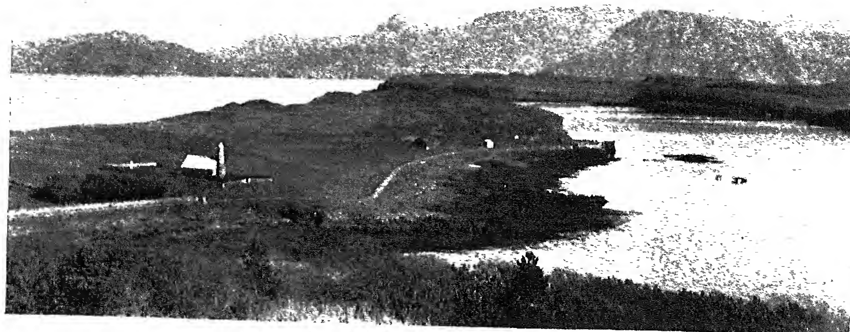
CONVOLVULACEÆ

Calystegia sepium Br. White Bindweed.
Very rare, Kinloch, Rhum, and Canna.

Convolvulus arvensis L. Small Bindweed.
Here and there on waste ground, Eigg and Muck.

SCROPHULARIACEÆ.

Digitalis purpurea L. Foxglove.
On all the islands, mostly on rocky ground along stream sides.



By Courtesy of the Royal Physical Society.

Fig. 6. The Islands of Rhum and Sanday from Canna.

Scrophularia nodosa L. Figwort.
Around Soay Harbour, streamsides on Eigg and on the Pabbay cliffs.

Mimulus Langsdorffii Donn.
In small amount on Soay.

Veronica hederaefolia L. Ivy-leaved Speedwell.
Waste ground, Eigg and Pabbay.

V. polita Fr.
Fields, Pabbay only; a new county record.

V. agrestis L. Field Speedwell.
Not common in cultivated ground on every island.

***V. arvensis** L. Wall Speedwell.
Much the same distribution as the preceding species.

†**V. serpyllifolia** L. Thyme-leaved Speedwell.
Well distributed nearly everywhere.

V. officinalis L. Common Speedwell.
Common, more especially in upland areas.

V. Chamaedrys L. Germander Speedwell.
Scattered on all the islands except Rhum, where it only occurs on Fionchra and near Rudha Port na Caranean.

V. scutellata L.
Rare in wet places on Eigg, Canna, Soay and Pabbay.

V. Beccabunga L. Brooklime.
In tiny streams on Eigg, Muck and Pabbay.

V. persica Poir. Buxbaum's Speedwell.
Waste places, Eigg, Canna and Soay.

Euphrasia borealis Towns. Eyebright.
Shores of Loch Scresort, Rhum, Eigg and Muck.

E. brevipila Burnat & Gremli.
Common in grass, most usually as var. *subglandulosa* on Eigg, Canna, Sanday and Soay; on Rhum much less frequent, but seen on Fionchra and Loch Scresort. Var. *gracilior* was obtained from Canna.

E. nemorosa Lohr.
Forms assignable to this occurred on Kilmory Bay and Loch Scresort, Rhum.

†**E. confusa** Pugsley.
The form *albida* was noted on Eigg, Muck and on Fionchra, Rhum.

E. curta Fr. ex **Wetts.**
An interesting, but minute plant, approaching var. *piccola* Towns., was found on Ruinsival and Barkeval, Rhum. Var. *glabrescens* Wettst., was recorded from Loch Scresort and Barkeval.

E. occidentalis Wettst. var. **calvescens** Pugsl.
Kilmory Bay, Rhum, Sanday, and Pabbay.

E. frigida Pugs.
Fionchra and Ruinsival, Rhum.

E. foulaensis Towns.
Forms, probably correctly assigned to this, were seen on Rhum.

E. micrantha Reich.
Widely spread on Rhum, Eigg and Soay.

E. scotica Wetts.
The type and var. *purpurascens* Pugsl. were not uncommon on Barkeval, Rhum.

Hybrids involving **E. brevipila, E. micrantha, E. nemorosa, E. occidentalis** and **E. curta** were collected on Rhum along the Kilmory and Kinloch valleys. They await study.

Bartsia Odontites Huds. Red Bartsia.
Frequent in various localities in the islands.
†**Pedicularis palustris** L. Marsh Lousewort.
Common in wet peaty places on all the islands, but Sanday.
†**P. sylvatica** L. Lousewort.
Everywhere common, including Sanday.
Rhinanthus minor Ehrh. Yellow Rattle.
Common in grassy places.
R. monticola Dr.
Fionchra, Rhum.
R. Drummond-Hayi Dr.
Fionchra, Rhum and Eigg.
R. stenophyllus Schur.
Eigg and Muck.
Melampyrum pratense Beauv. var. **montanum** Johnst.
Cow-wheat.
Very rare and local on Fionchra and Orval, Rhum, and on Canna; commoner on Soay.

OROBANCHACEÆ.

Orobanche rubra Sm. Broomrape.
Exceedingly local on thyme; Bloodstone Hill, Rhum, Canna and Muck.

LENTIBULARIACEÆ.

Utricularia minor L. Bladderwort.
Frequent in pools, Rhum, Muck and Soay.
U. major Schmidel. Bladderwort.
In pools and half-dry lochs, Soay and Muck.
U. ochroleuca Hartm.
Frequent in the Rhum lochs.
†**Pinguicula vulgaris** L. Butterwort.
Common in wet places.
P. lusitanica L. Pale Butterwort.
Only a little less common than the preceding, on most of the islands, but we possess no Canna, Sanday or Pabbay records.

LABIATÆ.

Mentha aquatica L. Horse-mint.
Rare, Kinloch, Rhum, Eigg, Muck and near the farm, Pabbay.
M. gentilis L.
Very rare; Kinloch, Rhum; a new county record.
M. piperita L. Peppermint.
On a bankside near the Post Office, Eigg.
Lycopus europaeus L. Gipsywort.
Shingle on Eigg and Soay, but very restricted in its range.
†**Thymus Serpyllum** L. Thyme.
Common on dry banks and well distributed.
T. ovatus Mill.
Found on Rhum and Eigg.
Scutellaria galericulata L. Skullcap.
Very rare and restricted in its distribution; on shingle on the north coast of Rhum, Eigg, Canna, Soay and Pabbay.
S. minor Huds. Lesser Skullcap.
Frequent in boggy places, Rhum, Eigg, Muck and Soay.

*†**Prunella vulgaris** L. Selfheal.
Abundant everywhere; often with flowers approaching those of *P. grandiflora.*

Stachys palustris L. Marsh Woundwort.
Rare near Rudha Port na Caranean, and in the small wood on the north side of Kinloch Burn, Rhum, also on Eigg, Sanday, Soay and Pabbay.

S. sylvatica L. Hedge Woundwort.
Always rare and local, but found on everyone of the large islands except Rhum.

S. ambigua Sm. The hybrid between the two preceding was noted on Poll nam Partan, Eigg.

S. arvensis L. Field Woundwort.
In fields on Eigg and Canna.

Galeopsis speciosa Mill. Hemp Nettle.
On cultivated ground, Eigg, Canna, Sanday, Muck and Soay.

G. Tetrahit L. Hemp Nettle.
As in the case of its ally, but also found rarely on Rhum.

Lamium amplexicaule L. Henbit.
Kinloch grounds, Rhum and Canna only.

L. mollucellifolium Fr.
Rare on cultivated ground, Eigg, Muck and Soay.

L. purpureum L. Red Dead Nettle.
Well distributed.

Teucrium Scorodonia L. Wood Sage.
Frequent, especially on dry banks.

Ajuga reptans L. Common Bugle.
On all the larger islands, but with only one Rhum station, a ravine on Mullach Mor.

†**A. pyramidalis** L.
Far from rare on bare places on steep banks. Rhum, Eigg, Canna and Muck; in Rhum and Muck widespread.

PLANTAGINACEÆ.

*†**Plantago Coronopus** L. Stag's Horn Plantain.
Frequent on the coasts of all the islands.

*†**P. maritima** L. Sea Plantain.
Likewise quite general on coasts; in Rhum also in the mountains, and there very variable.

*†**P. lanceolata** L. Ribwort Plantain.
Abundant and general.

***P. major** L. Greater Plantain.
Pathsides and waste ground; also common.

Littorella uniflora Aschers. Shoreweed.
Abundant in shallow water around the lochs on Rhum, Eigg and Soay.

CHENOPODIACEÆ.

***Chenopodium album** L. Goosefoot.
Not common although nearly everywhere on waste areas.

***Atriplex hastata** L.
On the shore, Rhum, Hyskeir, Sanday and Pabbay.

A. patula L. Orache.
Local on shores; Canna, Eigg, Muck.

A. glabriuscula Edmonst.
On the same islands.

Salicornia europaea L. Glasswort.
On the coast of Sanday.

Suaeda maritima Dum. Sea Blite.
Coast of Canna and Sanday.
Salsola Kali L.
On Laig Bay, Eigg only.

POLYGONACEÆ.

Polygonum Convolvulus L. Bindweed.
Rare; cultivated ground, Eigg.
*P. **heterophyllum** Lindm. Knotgrass.
On most of the islands, but not really plentiful.
P. **aequale** Lindm.
Found on Sanday; new to V.C. 104.
P. **Raii** Bab.
Rare; restricted to Eigg.
P. **Hydropiper** L. Water Pepper.
Rare and local; Rhum, Eigg, Muck, Soay.
*P. **Persicaria** L. Spotted Persicaria.
Of varying frequency throughout the islands.
*P. **amphibium** L. Water Persicaria.
Eigg, Sanday, Hyskeir and Soay; not common.
P. **viviparum** L.
Very rare and local; Orval, Rhum.
Oxyria digyna Hill. Mountain Sorrel.
Frequent on alpine rock ledges on the Rhum mountains, but nearly at sea level, Kinloch.
†**Rumex obtusifolius** L. Dock.
Quite common.
R. **crispus** L.
Also common, but more confined to the coast.
R. **glomeratus** Schreb.
Only seen on Eigg.
R. **longifolius** DC.
Kinloch, Rhum, also sparingly on Eigg, Canna and Sanday.
*†R. **Acetosa** L. Sorrel.
Plentiful generally.
†R. **Acetosella** L. Sheep's Sorrel.
Common but likes drier places.

EUPHORBIACEÆ.

Euphorbia Helioscopia L. Sun Spurge.
In fields on Eigg, Canna and Muck.
Mercurialis perennis L. Dog's Mercury.
On Eigg only, along a stream flowing into Laig Bay.

URTICACEÆ.

Ulmus montana Stokes. Wych Elm.
In the waterfall ravine Laig, Eigg, Canna and Muck.
***Urtica dioica** L. Nettle.
Plentiful near modern and abandoned habitation.
*U. **urens** L.
Round the lighthouse, Hyskeir only.

MYRICACEÆ.

Myrica Gale L. Sweet Gale.
Common on Soay and Eigg, but less so on Canna and Muck; strangely enough totally absent from Rhum.

CUPULIFERÆ.

Betula alba L. Silver Birch.
Local and rare on Rhum, Eigg, Canna, etc., but plentiful on Soay.

B. pubescens Ehrh. Birch.
Rare on Rhum and Soay; in sheltered gorges on Rhum.

Alnus rotundifolia Mill. Alder.
In the woods near the Harbour, Eigg; rare at Kinloch and Papadil, Rhum, common on Pabbay.

Corylus Avellana L. Hazel.
Widespread on the various islands, but never common except as scrub on the cliffs above Cleadale, Eigg.

Quercus Robur L. Oak.
In the woods, Eigg only.

Q. sessiliflora Salisb. Oak.
In sheltered stream gorges and on sea cliffs on Rhum, rarely inland as on Mullach Mor on the same island; much commoner on Eigg, but rarely on Soay. In most cases the plants exist as masses of distorted scrub, but a few well grown examples occur on each of the three islands. In Kinloch Castle there is an enormous oak stump unearthed when the Castle was built.

Fagus sylvatica L. Beech.
On Canna and Eigg.

SALICACEÆ.

Salix fragilis L. Crack Willow.
On Rhum and Eigg; probably planted.

S. alba L. White Willow.
On Eigg; also a likely introduction.

S. purpurea L. Purple Osier.
As in the case of the preceding species.

S. viminalis L. Osier.
In Rhum, Canna, Eigg and Soay.

S. aurita L. Eared Sallow.
Common on the larger islands.

S. aurita L. x **S. repens** L. (**S. ambigua** Sm.)
On Rhum, Eigg and Muck.

S. Caprea L. Goat Willow, Sallow.
Very rare on Eigg; more freely around Soay Harbour, Soay.

S. atrocinerea Brot. Sallow.
Never common; Rhum, Eigg, Soay and Pabbay.

S. atrocinerea Brot. x **S. aurita** L.
Pabbay only, now named x *S. varia* H.-Harr.

S. repens L. (Agg.) Creeping Willow.
On all the islands; diverse forms were found on Muck and Eigg, but they were linked up by a series of intermediates.

S. repens L. x **S. atrocinerea** Brot.
Only found in a little gorge south of Creag na h-Iolaire, Rhum; now named x *S. aquilae* H.-Harr.

S. herbacea L. Dwarf Willow.
Widespread and sometimes plentiful on the mountains on Rhum; also on the Sgurr, Eigg.

Populus tremula L. Aspen.
Frequent on lower cliffs of the mountains as well as along gorges; Rhum, Eigg, Eilean nan Each, Soay and Pabbay.

EMPETRACEÆ.

†**Empetrum nigrum** L. Crowberry.
Usually common on moorlands, but absent from Muck; on Eilean nan Each, on precipitous sea cliffs only.

ORCHIDACEÆ.

Malaxis paludosa Sw. Bog Orchid.
In a bog to the north of Loch Scresort, Rhum, and near Doire Mhor, Soay.

Listera cordata Br. Small Twayblade.
In a sheltered ravine in the east of Rhum.

L. ovata Br. Twayblade.
Rare near Cleadale, Eigg.

Orchis mascula L. Early Purple Orchis.
Rare on Fionchra and Monadh Dubh, Rhum, but not uncommon on cliffs on Muck and Eigg.

O. incarnata L. Marsh Orchid.
Scarce in marshy places on Eigg, Canna, Muck, Soay and Pabbay.

†**O. purpurella** Stph. Stephenson's Marsh Orchid.
Not at all rare on most of the islands; on Rhum only detected in a field near Kinloch.

†**O. elodes** Gris. Spotted Orchid.
Abundant generally and very variable; on Rhum, in particular, striking forms abound; not on Pabbay.

O. Fuchsii Dr. Spotted Orchid.
Very rare indeed on the same islands, but found on Pabbay.

O. elodes Gris. x **O. purpurella** Stph.
Rare on Muck.

Gymnadenia conopsea Br. Fragrant Orchid.
Rather common on Eigg, Canna and Muck; on Rhum on the banks of the stream issuing from Barkeval, also on Canna.

Leucorchis albida Mey.
Common in a pasture near the Harbour on Eigg; once on Orval, Rhum.

Coeloglossum viride Hartm. Frog Orchid.
Far from rare on dunes etc., Rhum, Eigg, Canna and Muck.

†**Platanthera bifolia** Reich. fil. Butterfly Orchid.
On Orval, Rhum, Poll nam Partan, Eigg, Sanday, Eilean nan Each and Soay; always rare.

P. chlorantha Reich. Butterfly Orchis.
Rare on Soay and Sanday.

IRIDACEÆ.

*†**Iris Pseudacorus** L. Iris.
Common in marshy places, more especially near the sea.

LILIACEÆ.

Allium ursinum L. Garlic.
Abundant in woods on Eigg, but only on a few cliffs near the sea on the north coasts of Rhum and Muck.

Scilla verna Huds. Vernal Squill.
Locally abundant on rocky outcrops, Canna and Sanday.

*†**S. non-scripta** Hoffm. & Link. Bluebell.
Abundant in woods on Eigg, plentiful in meadows etc., on Muck, but rare on cliff ledges near the sea elsewhere; found on Hyskeir.

Narthecium ossifragum Huds. Bog Asphodel.
Abundant in wet peaty habitats.

Tofieldia palustris Huds. Scottish Asphodel.
Locally plentiful on the Barkeval, Askival, Hallival group of mountains, Rhum.

JUNCACEÆ.

*†**Juncus bufonius** L. Toad Rush.
Plentiful in moist places along paths etc.

J. trifidus L.
Rare, damp alpine crevices, Rhum.

†**J. squarrosus** L. Heath Rush.
Very abundant in heathy grassy places.

***J. Gerardi** Lois.
Locally common except on Muck; always on the coast.

J. tenuis Willd.
Well established by roads and paths, Kinloch, Rhum.

†**J. effusus** L. Soft Rush.
Frequent in wet places.

J. conglomeratus L. Soft Rush.
Abundant in damp localities.

†**J. bulbosus** L. Lesser Jointed Rush.
Also common enough.

***J. articulatus** L. Shining-fruited Rush.
Common generally.

J. sylvaticus Reich. Wood Rush.
Locally common; Rhum, Eigg, Canna and Pabbay.

J. triglumis L.
Rare and local; Barkeval and Hallival, Rhum. The form is unusual and requires further study.

J. capitatus Weigel.
Local on bare peaty ground along the Kinloch Burn, Rhum. This provides a second Scottish station for this very rare rush, the first being on Raasay where the species was detected on our 1936 expedition.

Luzula sylvatica Gaud. Large Wood Rush.
Locally plentiful, but not on Muck.

†**L. campestris** DC. Field Wood Rush.
Frequent in grassy places.

*†**L. multiflora** DC.
Common on damp heaths with var. *congesta* Lej.

L. pilosa Willd.
Sparingly on Muck.

TYPHACEÆ.

Sparganium angustifolium Michx. Floating Bur Reed
Frequent in lochs and pools, Rhum and Soay.

S. simplex Huds. Bur Reed.
Rare, Eigg and Soay.

LEMNACEÆ.

Lemna minor L. Duckweed.
Wet places on Canna; rare and local.

NAIADACEÆ.

Triglochin palustre L. Marsh Arrow Grass.
Frequent in wet places.

***T. maritimum** L. Sea Arrow Grass.
Rather rare, although locally plentiful in salt marshes.

†**Potamogeton polygonifolius** Pourr. Pondweed.
Abundant in lakes, pools etc.

†**P. natans** L. Floating Pondweed.
Not common, Eigg, Eilean nan Each and Soay.

P. alpinus Balb.
In pools above the area between Kilmory Bay and Shamhnan Insir, Rhum; new to the county.

***Ruppia maritima** L.
In a pool Harris, Rhum and common in similar places on Hyskeir.

Zostera marina L. Grass Wrack.
Scarce, washed ashore on Eigg and Soay.

†**Z. Hornemanniana** Tutin. Grass Wrack.
Common in pools on the Hyskeir reef; new to V.C. 104.

CYPERACEÆ.

*†**Eleocharis palustris** Roem. & Schult.
Common in shallow water generally.

E. multicaulis Sm.
Common on Rhum, Muck, Eigg and Soay.

Scirpus pauciflorus Lightf.
Common in peaty bogs.

S. caespitosus L. Deer Grass.
Very abundant.

S. fluitans L.
Common, but not on Canna.

S. setaceus L.
Fairly common although not seen on Muck.

***S. maritimus** L. Sea Club Rush.
Locally abundant Canna and Sanday as well as on Hyskeir.

S. rufus Schr.
Salt marshes, Eigg, Canna, Sanday.

†**Eriophorum vaginatum** L. Cotton Grass.
Locally abundant on all of the isles.

†**E. angustifolium** Roth. Cotton Grass.
Even more abundant, and generally distributed.

Rynchospora alba Vahl. Beaked Rush.
Quite common, Rhum, Eigg, Soay and Pabbay.

†**Schoenus nigricans** L.
Also well distributed and common.

Cladium Mariscus Por.
In Loch Doire an Lochain, Soay and a pool on Muck; the second and third records respectively, for V.C. 104.

Carex dioica L.
Not uncommon in the corries on Rhum, also on Eigg and Pabbay.

†**C. pulicaris** L. Flea Sedge.
Common on all the islands.

***C. arenaria** L. Sand Sedge.
Generally common on dunes in the islands; especially abundant on Hyskeir.

C. paniculata L.
Common in one restricted locality in the centre of Muck; a new county record.

***C. vulpina** L. Fox Sedge.
Rare and local on all the southern islands, but often only on the coast.

†**C. echinata** Murr. Starry Sedge.
Abundant in moist places.

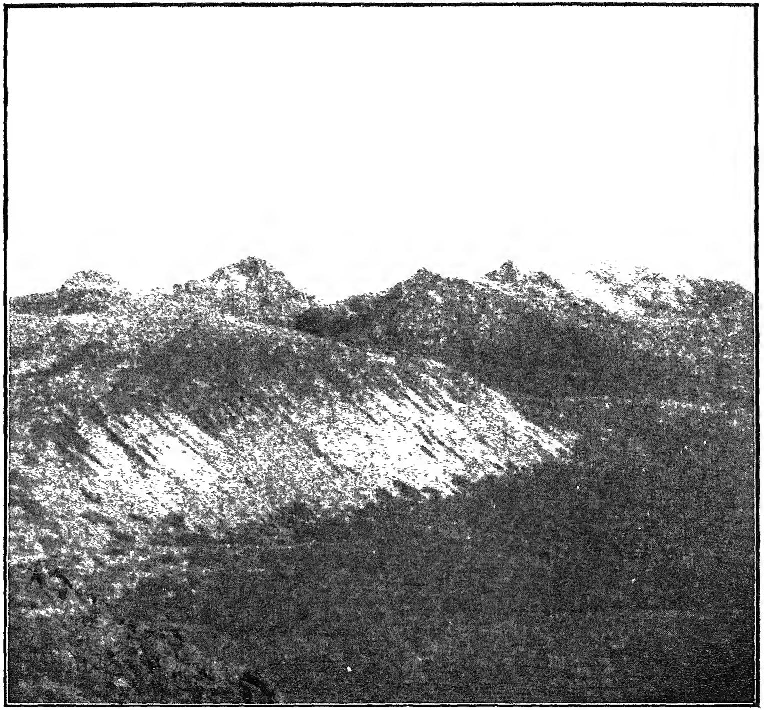


Fig. 7. The Mountain Massif on Rhum, showing Hallival, Askival, Trallval, Ainshval and Sgurr nan Gillean.

C. remota L.
Only noted on Eigg and Pabbay.
C. leporina L.
Not very common, but widespread on the islands.
C. rigida L.
On several of the higher mountains on Rhum.
C. Goodenowii Gay. Common Sedge.
Plentiful everywhere.
C. diversicolor Crantz. Glaucous Sedge.
Quite common, but apparently not collected on Canna.
C. limosa L. Bog Sedge.
Rare and local; only in a small loch near Minshall, and in a similar station on Barkeval, Rhum.
†**C. pilulifera** L. Pill-headed Sedge.
Occasional, especially in the uplands, Rhum and Eigg.
†**C. caryophyllea** Latour.
Not uncommon in most islands.
C. pallescens L.
Frequent in wet places, Rhum, Eigg, Soay.
†**C. panicea** L. Carnation Grass.
Generally fairly common.
C. atrofusca Schkuhr.
Exceedingly rare; between Orval and Ard Nev, Rhum. An important new county record for a rare sedge previously only known from V.C. 88.
C. capillaris L.
Also rare on Sron an t-Saighdeir, Rhum; also new to the county.
C. helodes Link.
Pabbay only.
†**C. binervis** Sm.
Well distributed and not rare.
C. fulva Host. Tawny Sedge.
Not uncommon, Rhum, Eigg and Sanday.
C. fulva Host. X **C. Œderi** var. **œdocarpa** And.
Occasionally where the two overlap on Rhum.
C. distans L.
Only collected on Hyskeir.
C. extensa Good.
Rare and local, rocky stations on the coast, Sanday.
†**C. flava** L.
Not very common, but fairly general.
C. Œderi Retz. var. **œdocarpa** And.
More common than the last, but on much the same habitats.
C. inflata Huds. Slender-beaked Sedge.
Locally common, pools etc., Rhum, Eigg, Soay, Pabbay.
C. vesicaria L.
Rare, boggy ground north of Barkeval, Rhum; also on Eigg and Muck.

GRAMINEÆ.

Phalaris arundinacea L. Ribbon Grass.
Sparingly scattered on Rhum, Eigg and Canna.
P. canariensis L. Reed Canary Grass.
Occurred as a casual on Rhum.
*†**Anthoxanthum odoratum** L. Sweet Vernal Grass.
Common on every island.
Alopecurus myosuroides Huds. Slender Foxtail.
Weed of cultivation; on Canna only; new to the vice-county.

A. geniculatus L. Floating Foxtail.
Common in wet situations on all islands.

A. pratensis L. Meadow Foxtail.
Very rare, Rhum and Muck only.

Phleum pratense L. Timothy.
Rare on Rhum, Eigg, Canna and Muck; probably introduced.

Agrostis canina L.
Very common on all islands, but not seen on Muck, although it probably exists there.
The mountain form var. *elatior* Hartm. was found on Barkeval, Rhum, where specimens were collected with two-flowered spikelets.

*†**A. alba** L. Fiorin.
Plentiful on all islands.

*†**A. tenuis** Sibth.
Very common on all islands.

A. nigra With.
On sandy ground near the shore, on Canna only; new to V.C. 104.

Ammophila arenaria Link. Sea Mat Grass.
On the dunes near Kilmory and Shamhnan Insir, Rhum, Laig Bay, Poll nam Partan, Eigg and Sanday.

Aira caryophyllea L. Silvery Hair Grass.
Fairly common on pathways and dry stony places on all islands except Soay, Sanday and Eilean nan Each.

†**A. praecox** L. Early Hair Grass.
Common on paths and walls of old crofts on all islands.

†**Deschampia caespitosa** Beauv. Tufted Hair Grass.
Of frequent occurrence on all islands except Soay, where it was absent.

D. alpina Roem. & Schult. Alpine Hair Grass.
This rare grass was found on the mountains of Askival, Hallival, and Sgurr nan Gillean, Rhum, at elevations exceeding 2,250 feet; a new county record.

D. flexuosa Trin. Wavy Hair Grass.
Plentiful on Rhum, Eigg, Canna, Soay and Pabbay.

Holcus mollis L. Creeping Soft Grass.
Common by paths and in shady places on every island, but particularly abundant on Soay.

*†**Holcus lanatus** L. Yorkshire Fog.
Common everywhere.

Trisetum flavescens Beauv. Golden Oat Grass.
Very rare; only found in one meadow near Laig Bay, Eigg; new to V.C. 104.

†**Avena pubescens** Huds. Downy Oat Grass.
In meadows and on cliffs on Rhum, Eigg, Canna, Sanday and Muck.

Avena strigosa Schreb. Bristle-pointed Oat.
Not uncommon as weed of Oat fields on Eigg and Pabbay.

***Arrhenatherum elatius** Mert. & Koch. Tall Oat Grass.
Common on Rhum, Canna, Eigg and Soay; var. *pauciflora* occurs on Eigg.

A. tuberosum Gilib. Bulbous Oat Grass.
Frequent in waste places on all islands.

†**Sieglingia decumbens** Bernh. Decumbent Heath Grass.
Everywhere common.

Phragmites communis Trin. Common Reed.
In lochs and wet places on Rhum, Eigg, Canna, Muck and Soay.

†**Cynosurus cristatus** L. Dogstail.
Abundant on every island.

†**Koeleria gracilis** var. **britannica** Domin. Crested Hair Grass.
In grassy places near the sea on every island except Soay and Pabbay.

*†**Molinia caerulea** Moench. Moor Grass.
Exceedingly common on moorlands everywhere.

*†**Catabrosa aquatica** Beauv.
Where streams enter the sea on Rhum, Eigg and Muck.

†**Dactylis glomerata** L. Cocksfoot.
Not at all common, but found near cultivation on all islands except Pabbay.

*†**Poa annua** L. Annual Meadow Grass.
Plentiful everywhere.

P. **glauca** Vahl.
A rare mountain grass found only on Fionchra and Bloodstone Hill, Rhum, but there in considerable quantity.

P. **nemoralis** L. Wood Meadow Grass.
Uncommon in woods near Kinloch Castle, Rhum, on shady cliffs on Canna, and near Laig Bay, Eigg. The mountain form, var. *caesia* Gaud., was found only on Fionchra, and the Trallval-Ruinsival Cliffs, Rhum.

*†P. **pratensis** L. Smooth-stalked Meadow Grass.
Everywhere common. The variety *subcoerulea* Sm., wi.h short blue-green leaves, was found in pastures on Muck and Eilean nan Each.

P. **palustris** L.
In swamp at the side of a stream near Tarbet, Canna; new to V.C. 104.

*†P. **trivialis** L. Rough-stalked Meadow Grass.
Of frequent occurrence on every island.

Glyceria fluitans Br. Floating Sweet Grass.
At borders of streams and in marshy places on all islands.

G. **declinata** Breb.
Uncommon in wet situations on Rhum, Eigg, Soay and Pabbay.

G. **maritima** Mert. & Koch.
Very local in salt marshes on every island except Eilean nan Each and Pabbay.

Festuca rottboellioides Kunth.
Rare on sand dunes near Kilmory, Rhum and on Sanday; new to V.C. 104.

F. **bromoides** Huds.
Of restricted distribution; in stackyard of farm, Eigg.

F. **capillata** Lam. Fine-leaved Sheep's Fescue.
Very sparingly distributed on Rhum.

†F. **vivipara** Sm. Viviparous Sheep's Fescue.
One of the commonest grasses on all the islands.

*†F. **rubra** var. **vulgaris** Gaud. Red Fescue.
Common everywhere, particularly near the sea and on mountain slopes. The variety *glaucescens* Hig. & Hier. was found on cliffs on the coast of all islands except Canna, Sanday and Soay.

F. **prolifera** Fern.
This grass, collected on Barkeval, Rhum in 1937, and then recognised as a novelty, forms an important addition to the European Flora. It has only been recorded previously from New Hampshire, Gaspé Peninsula, Anticosti and Newfoundland (all American localities).

F. **pratensis** Huds. Meadow Fescue.
Exceedingly rare; one or two plants were found in a meadow on Rhum; new to V.C. 104.

F. arundinacea Schreb.
We only possess Sar··ar specimens, but it no doubt occurs elsewhere.

Bromus hordaceus L. . Brome Grass.
As weed of arable ıa all islands except Pabbay.

†**Brachypodium sylvaticum** .. . & Schult. Wood False Brome Grass.
Fairly common everywhere in shady places.

*†**Lolium perenne** L. Perennial Rye Grass.
Common everywhere.

L. multiflorum Lam. Italian Rye Grass.
Introduced on Eigg, Canna, Pabbay and Muck.

***Agropyron repens** Beauv. Couch Grass.
Not uncommon on low lying land on all islands except Soay and Pabbay.

A. pungens Roem. & Schult.
Rare; only near the sea on Canna. The variety *aristatum* Hackel was noted in similar situations to the preceding on Rhum and Canna; new to V.C. 104.

A. junceum var. **megastachyum** Fr. Sea Couch Grass.
Uncommon on sand dunes on Rhum, Canna and Sanday.

†**Nardus stricta** L. Moor Mat Grass.
Abundant on every island.

Elymus arenarius L. Sand Lyme Grass.
Introduced as a sand binder on Eigg.

CONIFERÆ.

†**Juniperus sibirica** Burgsdorf. Dwarf Juniper.
Sparingly distributed in rocky situations on Rhum, Eigg, Canna, Muck and Soay; sometimes also on sea-cliffs.

FILICES.

Hymenophyllum peltatum Desv. Filmy Fern.
Locally plentiful on damp sheltered rocks on Rhum and Eigg; also in the wood south of Soay Harbour.

†**Pteris aqualina** L. Bracken.
Locally very abundant.

Cryptogramme crispa Br. Parsley Fern.
Confined to Rhum where it occurs on the cliffs of Orval and Sgurr nan Gillean.

†**Blechnum Spicant** With. Hard Fern.
Common on moorlands everywhere.

Asplenium Adiantum-nigrum L. Black Spleenwort.
Frequent enough in rocky situations.

†**A. marinum** L. Sea Spleenwort.
Abundant on the sea cliffs.

A. viride Huds. Green Spleenwort.
Restricted to the screes on the north side of Ruinsival, Rhum and the Pabbay cliffs.

A. Trichomanes L. Spleenwort.
Common in rock crevices.

A. Ruta-muraria L. Wall Rue.
Not really plentiful on limestone outcrops and Bloodstone Hill, Rhum; also on Eigg, Canna and Soay.

*†**Athyrium Filix-foemina** Roth. Lady Fern.
Fairly generally distributed and common.

Fig. 8. The Isle of Canna, Bloodstone Hill and Glen Guirdil from Orval.

Phyllitis Scolopendrium Newm. Hart's Tongue Fern.
Very rare in ravines and caves on the north coast of Rhum; in similar places on Eigg and Pabbay.

Cystopteris fragilis Bernh. Bladder Fern.
Rather rare on alpine rocks, Rhum and on Eigg.

Polystichum aculeatum Roth. Prickly Shield Fern.
Rare in damp gorges and on shaded cliffs, Rhum and Eigg.

Lastrea montana T.Moore. Sweet Mountain Fern.
Local and not common, Rhum, Soay and Pabbay.

†**L. Filix-mas** Presl. Male Fern.
Common enough in shady places.

L. spinulosa Presl.
Slightly commoner than the last.

†**L. aristata** Rendle & Britten. Broad Shield Fern.
Fairly common throughout.

L. aemula Brackenridge.
Rocky situations, Rhum and Eigg.

†**Polypodium vulgare** L. Common Polypody.
Rather common on all the islands.

Phegopteris Dryopteris Fée. Oak Fern.
Very rare and only recorded from screes on the western slopes of Orval.

P. polypodioides Fée. Beech Fern.
Much more frequent than its ally, cliff ledges etc., Rhum, Eigg, Canna and Soay.

Osmunda regalis L. Royal Fern.
Well distributed and locally abundant on Rhum, where really magnificent specimens occur; also seen sparingly on Pabbay.

***Ophioglossum vulgatum** L. Adder's Tongue Fern.
Rare on Kilmory dunes, Rhum, behind Laig dunes, Eigg, and on grassy mounds, Hyskeir; new to V.C. 104.

Botrychium Lunaria Sw. Moon-wort.
Rare in the same habitats as the last species on Rhum and Eigg, although once taken at 2,000 feet on Askival, Rhum; fairly common on the dunes on Muck.

EQUISETACEÆ.

Equisetum maximum Lam. Great Horse-tail.
Very rare; woods around Loch Scresort, Rhum, wet places on cliffs above the Singing Sands, Eigg.

E. arvense L. Common Horse-tail.
On waste and cultivated ground, Rhum, Eigg and Canna.

E. sylvaticum L. Wood Horse-tail.
Occasional in damp moorland localities, Rhum, Eigg and Muck.

E. palustre L. Marsh Horse-tail.
Fairly frequent in wet situations, Rhum, Eigg, Soay and Pabbay.

†**E. limosum** L. Smooth Horse-tail.
Locally plentiful in lochs.

E. variegatum Schleich.
Not uncommon on the Kilmory sand-dunes, and also on a sandy exposure, Glen Guirdil, Rhum.

LYCOPODIACEÆ.

Lycopodium Selago L. Fir Club Moss.
Universally distributed on the moors of Rhum, Eigg, Muck and Soay.

L. clavatum L. Common Club Moss.
Rare and only observed on Orval and Fionchra, Rhum.

L. alpinum L. Alpine Club Moss.
Locally common as on Orval, Black Hill, and Bloodstone Hill, Rhum.

SELAGINELLACEÆ.

Selaginella selaginoides Gray. Common Selaginella.
Quite common in bare damp places on all the islands.

Isoetes echinospora Durieu. Quillwort.
Plentiful in small lochs on Mullach Mor, and in a pool near Bloodstone Hill, Rhum.

CHAROPHYTA.

Chara fragilis Desv.
Pools on Eigg.

C. delicatula Agardh.
In a pool on Muck; also on Rhum and Canna.

†**Nitella opaca** Agardh.
On Eilean nan Each.

N. translucens Agardh.
In Glen Shellesder, Rhum, also on Soay.

NOTEWORTHY PLANTS FROM NORTH UIST, BALESHARE, MONACH ISLANDS, HARRIS, TARANSAY, MINGULAY AND BERNERAY, (V.C. 110).

By W. A. CLARK, B.Sc., Ph.D.

In 1938 Dr. G. Heslop Harrison and myself spent the Easter vacation on North Uist and Harris, and whilst on North Uist we took the opportunity of examining the neighbouring island of Baleshare. This preliminary expedition, which enabled us to study the early spring flora was followed by a second to the same islands in July of the same year. On this occasion, too, the Monach Islands and Taransay were surveyed, my companions on this trip being Mr. W. Campion and Dr. A. Ritchie.

Although, as a preliminary to our County Flora of the Inner and Outer Islands, it is intended to publish a complete list of the plants detected in N. Uist, Baleshare, Monach Islands, Harris and Taransay, the present paper places on record the plants from these islands which seem to demand special treatment.

As far as rare plants are concerned, the localities now cited afford extensions of their known distribution in the Outer Islands (V.C. 110). In a few cases records have been included from Mingulay and Berneray (Barra Isles), the flora of which was investigated by myself in the summer of 1937[1].

Thalictrum alpinum L.
Quite common in the gullies of the cliffs forming the north face of Cnoc Eadar Dà Bheinn, N. Harris.

Ranunculus bulbosus L.
Rare on Machair Leathann, N. Uist and the dunes, Luskentyre, S. Harris.

R. Ficaria L.
Not common and confined to sheltered cliffs; North Lee and Maari, N. Uist; Toe Head, S. Harris and near Loch an Dùin, Taransay.

Arabis hirsuta Scop.
Sparingly on the dunes near Dùn Chlach in the east of Taransay.

1 "The Flora of the Islands of Mingulay and Berneray." Proc. Durham Univ. Phil. Soc., Vol. X., Part I, pp. 56-70.

Erophila verna E. Meyer.
Locally abundant on the machairs of N. Uist, Baleshare, Monach Islands and Harris, when visited early in the summer.

Cochlearia danica L.
Not uncommon on Machair Leathann near Sollas, N. Uist, but plants very dwarf.

V. Curtisii Forster.
On the machair of all the islands except Mingulay and Berneray.

Silene maritima With.
Rare and local; on the sea cliffs of Toe Head, S. Harris, and of Taransay, but as a strand plant on the Monachs.

S. acaulis L.
Only observed on the cliffs of Skate Point, Berneray, and on the north slope of Hecla, Mingulay.

Sagina nodosa Fenzl.
Rare and only detected on wet dunes, Ceann Iar, Monach Group.

Oxalis Acetosella L.
Not common and confined to sheltered cliffs, North Lee, N. Uist; and south shore of East Loch Tarbert, Harris.

Ilex Aquifolium L.
On the cliffs of the south side of East Loch Tarbert, Harris.

Ulex europaeus L.
One large bush observed near Loch Minish, N. Uist; also at Tarbert, Harris.

Cytisus scoparius Link.
On a rocky headland near the Manse, Tarbert, but probably planted.

Rubus saxatilis L.
On the sheltered banks of a streamlet, Toe Head, S. Harris.

Alchemilla alpina L.
Abundant on the north side of Clisham, N. Harris, just below the summit.

Rosa glaucophylla Winch. Agg.
(a) Var. **subcristata** (Baker) H.-Harr.
f. **adenophora** (Gren.) H.-Harr. Near Eaval, N. Uist.
(b) Var. **orbicans** Almq. Only on the sheltered cliffs of the south shore of East Loch Tarbert, Harris. New to Scotland.

R. mollis Sm. Agg.
Var. **glandulosa** W.D. A few plants observed on the cliffs of Nisabost Point, S. Harris, and on the sheltered banks of a small stream just west of Dùn Chlach, Taransay. These plants were flowering and fruiting abundantly, a condition not often met with among roses in the Outer Islands.

R. Sherardi Dav.
Var. **Cookei** H.-Harr. One plant of this endemic rose was detected on the banks of a streamlet near the foot of the west slope of Eaval, N. Uist.

Saxifraga oppositifolia L.
Common in some of the wet gullies of the cliffs of Cnoc Eadar Dà Bheinn, N. Harris; not observed on Clisham, N. Harris, the highest mountain in the Long Island.

S. stellaris L.
Also on the cliffs of Cnoc Eadar Dà Bheinn, N. Harris; on Clisham, N. Harris, and Uamasclett, S. Harris.

S. tridactylites L.
Locally common on the dunes of Baleshare, growing in association with *Erophila verna* (L.) Meyer, and exceedingly dwarf specimens of *Cardamine hirsuta* L.

Sedum roseum Scop.
Locally abundant on the cliffs of Eaval, N. Uist, of Cnoc Eadar Dà Bheinn, N. Harris, and of Uamasclett, S. Harris; also on the sea cliffs of Toe Head, S. Harris, and of Taransay, Mingulay, and Berneray.

Hippuris vulgaris L.
Common in ditches of the Bayhead region of N. Uist, and Baleshare; also round the margin of Loch Sniogravat, Ceann Ear of the Monach Group.

Epilobium angustifolium L.
On the Islands, this plant is confined to rocky ledges of sheltered cliffs, and in those with which this paper deals it was found on the north slope of Eaval, N. Uist, and near Sythe Harbour, Taransay. This island plant is quite distinct from the mainland form, differing chiefly in leaf shape and in the colour of the flower which, when the plant does flower, is deep purple; in addition, however, the habit of this plant is quite characteristic. We consider it to be a very distinct variety, and are reserving it for special treatment and description later.

Eryngium maritimum L.
Rare on the seaward edge of the machair opposite Kirkibost Island, N. Uist, but common enough on the storm beach, Mingulay Bay, Mingulay.

Apium nodiflorum Reichb.
In ditches and wet areas of the dunes on N. Uist, Baleshare, and Ceann Ear, Monach Group.

A. inundatum L.
On the three islands mentioned above and in similar habitats to the preceding species.

Œnanthe Lachenalii C. Gmel.
On Ceann Ear, Monach Group, near Loch Sniogravat.

Ligusticum scoticum L.
Common locally; on the sea cliffs of Toe Head, S. Harris, and of Taransay, Mingulay and Berneray.

Caucalis Anthriscus Huds.
As a weed of cultivation, Taransay.

Hedera Helix L.
Sparingly on the cliffs in the south of Maari, N. Uist; also on the cliffs of the south shore of East Loch Tarbert, Harris, and of Mingulay Bay, Mingulay.

Inula Helenium L.
On waste places near the village of Paible and near the old ruined houses at Clach an Teampnill, Taransay.

Tussilago Farfara L.
Rare and only observed on the dunes at Luskentyre, S. Harris.

Arctium nemorosum Lej.
On waste ground near the village of Paible, Taransay.

Saussurea alpina DC.
On the cliffs of Cnoc Eadar Dà Bheinn, N. Harris.

Centaurea nemoralis Jord.
Abundant on the machairs of N. Uist, Monachs, Harris and Taransay.

Hieracium L.
The following species of *Hieracium* have all been determine by Mr. Pugsley to whom I tender my sincere thanks.

H. iricum Fr.
On the banks of the Skeaudale River, N. Harris.

H. caledonicum F.J.Hanb.
Also on the banks of the Skeaudale River.

H. clovense Linton.
Detected on rock ledges of the lower cliffs, north face, Eaval, N. Uist; a very interesting find in view of the discovery of *Carex Halleri* Gunn. on the summit cliffs of the same mountain.

H. nitidum Backh.
Cliffs facing Sythe Harbour, Taransay.

H. Pilosella L. var. **nigrescens** Fr.
On the banks of the small stream near Dùn Chlach, Taransay.

Taraxacum laevigatum DC.
Collected on the dunes of N. Uist, Monachs, Baleshare, Harris and Taransay.

Vaccinium Myrtillus L.
Exceedingly local and rare, and only in sheltered situations; N. Uist, Harris, and Taransay.

V.. Vitis-Idaea L.
On Clisham, N. Harris.

Lysimachia nemorum L.
Rare, and another of the plants confined to the sheltered cliffs of the south shore of East Loch Tarbert, Harris.

Centunculus minimus L.
Round the margin of a small loch just west of Paible, Taransay.

Samolus Valerendi L.
Observed on marshy ground near Loch Sniogravat, Ceann Ear, Monach Group.

Gentiana baltica Murb.
Growing alongside *G. campestris* L. on the dunes near Dùn Chlach, Taransay.

Echium vulgare L.
Not uncommon on the dunes near Dùn Chlach, and on the machair near Paible, Taransay.

Veronica Beccabunga L.
In a marsh near Sollas Aerodrome, N. Uist.

Euphrasia curta Fr. var. **glabrescens** Wettst.
Collected on the Monach Islands.

Scutellaria galericulata L.
Round the shores of Loch Skealtar, N. Uist, and on the south shore of East Loch Tarbert.

Stachys palustris L.
Confined to the banks of a small stream, Lochmaddy, N. Uist.

Teucrium Scorodonia L.
Uncommon and only noted from the banks of the Skeaudale River, N Harris.

Suæda maritima Dum.
In a salt marsh near Carinish, N. Uist.

Oxyria digyna Hill.
Common on the cliffs of Cnoc Eadar Dà Bheinn, N. Harris, and also observed on the sea cliffs in the west of Mingulay.

Myrica Gale L.
Surprisingly rare, and only observed on the shore of Loch Dùn an t-Siamain, near Eaval, N. Uist.

Corylus Avellana L.
A few stunted specimens seen on the sheltered banks of the Skeaudale River, N. Harris.

Salix viminalis L.
On Toe Head, S. Harris.

S. atrocinerea Brot.
Only recorded from the cliffs of the south shore of East Loch Tarbert, Harris.

S. arbuscula L. x **S. lapponum** L. (=**S. spuria** F.B.White *non* Willd).
A specimen of this very rare hybrid was discovered in a batch of Willows collected from Glen Skeaudale, N. Harris; determined as a *lapponum* form by Prof. Heslop Harrison and assigned to that stated here by Kew.

S. herbacea L.
First detected on the summit cliffs of Crogary More (588 ft.), N. Uist where it is very rare; later it was found in quantity on the summit of Eaval (1138 ft.), N. Uist. Strangely enough it has not been observed on the mountains of Harris so far visited, though it occurs abundantly on Beinn Mhor, S. Uist.

Listera cordata Br.
Occurs sparingly with *Hymenophyllum unilaterale* Bory on the heather clad slopes at the foot of the cliffs facing Sythe Harbour, Taransay.

Scilla verna Huds.
Generally distributed over both Mingulay and Berneray.

Lemna minor L.
Abundant round the margin of Loch Sniogravat, Ceann Ear, Monach Group.

Alisma ranunculoides L.
In the same loch as the *Lemna*.

Juncus balticus Willd.
Common in the wetter areas of the dunes, Baleshare.

J. maritimus Lam.
On the sandy margin of a salt marsh near Carinish, N. Uist.

Scirpus Tabernaemontani Gmel.
In Loch Laxadale, Harris, and in one of the lochs between Carinish and Eaval, N. Uist.

Cladium Mariscus Br.
In Loch Fada near Eaval, N. Uist.

Carex Halleri Gunn.
This very rare and interesting sedge was discovered in a gorge leading to the summit cliffs of Eaval, N. Uist; my determination has been confirmed by Mr. E. Nelmes.

C. rigida Good.
Also collected from the summit cliffs of Eaval, N. Uist.

C. limosa L.
Sparingly round the shores of a small loch just west of Clett an Dùin, Taransay.

Phalaris arundinacea L.
In a ditch near Carinish, N. Uist.

Phleum pratense L.
Only recorded from Bayhead, N. Uist.

Deschampsia caespitosa Beauv.
A very rare grass in the Outer Hebrides and only recorded from Harris, where it occurs on the sea cliffs of the south side of East Loch Tarbert, and on the cliffs of Cnoc Eadar Dà Bheinn and of the summit of Clisham. When the last mentioned habitat was visited, the plants were not in flower, but it is just possible that they may turn out to be

Deschampsia alpina R. & S., which we collected from a similar habitat on the summits of Askival and Sgurr nan Gillean, Rhum, in 1937 and 1938.

D. setacea Richter.
Probably common enough but overlooked; a number of plants observed in some small peaty pools bordering the road between Loch Bruist and Loch Horisary in the Bayhead district of N. Uist.

Dactylis glomerata L.
Another very rare grass in the Outer Isands and only detected at Bayhead and Lochmaddy, N. Uist.

Agropyron junceum Beauv. var. **megastachyum** Fr.
Sparingly among the Marram grass on all the islands.

Phyllitis Scolopendrium Newm.
A fern not often noted in the Long Island, and collected on the sheltered banks of the streamlet just south of Dùn Chlach, Taransay; also on the walls round a garden, Lochmaddy, N. Uist, but probably not native there.

Polystichum aculeatum Roth.
Just as rare as the Hart's Tongue Fern and on the same sheltered bank.

Equisetum variegatum Scleich.
On a wet clayey exposure, Nisabost Point, S. Harris.

SOME BRYOPHYTES OF THE SMALL ISLES PARISH OF INVERNESS-SHIRE AND OF THE ISLAND OF SOAY.

by

K. B. Blackburn and E. M. Lobley.

This list forms part of a series of papers on the biology of the Hebrides emanating from King's College, as a result of the Expeditions organized by Professor J. W. Heslop Harrison, D.Sc., F.R.S., during the last few years. The main collections, on which the paper is based, were made by one of the authors (K.B.B.) during the expeditions of 1937 and 1938. To these are added a set collected by Dr. George Heslop Harrison round Cleadale, Isle of Eigg, in April 1935, two batches sent by Mrs. McEwen from the Isle of Muck in 1938 and one from the tiny lighthouse island of Hyskeir contributed by the lighthouse keeper, Mr. David L. White, in March 1939.

Two published lists are available which concern our area: one by Mr. C. V. B. Marquand from Rhum, published in the Proc. Linn. Soc., Session 1933-1934, Pt. I, p. 27, and the second in the report on "The Natural History of Canna and Sanday, Inner Hebrides" from the Glasgow University Canna Expeditions of 1936 and 1937, published in Proc. Roy. Physical Soc. Vol. XXIII, Pt. I, pp. 1—80. In the latter the Bryophyte work was carried out by Miss H. Muggoch and Miss M. Smith. These lists have been incorporated, but the locality is accompanied, in each case, by a distinguishing mark: (M) and (G) respectively.

The list cannot be considered in any way exhaustive, as the collections were only made casually, in the intervals of other work, and the number of localities represented is small. On Eigg, in addition to Dr. George Heslop Harrison's list, a single collection was made on the Sgurr*; on Sanday and Canna only an odd specimen or two was collected which added but a single species to the Glasgow list; the Soay collections were chiefly made with a view to Sphagna, so the mosses of drier situations are not included. Plants from Rhum are better

*A further expedition to Eigg in June, 1939, made while this was in the press, will add a considerable number of species to the list, including several new records for V.C. 104. This will be reported later.

represented and the wideness of their distribution can be judged from the number of place names mentioned, since the list has been compiled, almost solely, from actual specimens sent to the second author and named by her.

Besides thanking the contributors mentioned above, we also wish to acknowledge our indebtedness to Mr. J. B. Duncan of Berwick for kindly confirming the new records for mosses and hepatics, and to Mr. A. Thompson for verifying the records of Sphagna.

The total number of species, for all the islands referred to, is 205, of which, 28 were not found by us, but occur in the papers already quoted. The individual islands show the following number of species: Rhum 132, Canna with Sanday 98, Eigg 67, Muck 58, Soay 24 and Hyskeir 12. Each of the islands has some species not listed from elsewhere: Rhum 44, Canna and Sanday 15, Eigg 16, Muck 13, Soay 4 and Hyskeir 1. It is curious that Canna, which had certainly the most systematic study, has a notably small proportion of these apparently localized plants.

There are only 15 new records for V.C. 104; these are marked with a star* in the list. All of Mr. Marquand's Rhum list were new records. Those species and the ones starred in the Glasgow paper, as new, are here marked with a dagger†. Other records have been forestalled by recent collections in Skye by E. M. L., and by plants collected on Raasay etc. during Professor Harrison's expeditions.

In addition to the living mosses included above, a small number have been identified in the peats, from the islands, which were collected for a forthcoming paper on the pollen-statistics of the Inner Hebrides by one of the authors (K.B.B.). These are included in the list but do not add any new species.

The general vegetation and geology of these islands have already been described in the introduction to the paper on the Flowering Plants, edited by Professor Harrison (Proc. Univ. Durham Phil. Soc., Vol. 10, Pt. 2, 1939), but it may be helpful here to mention the type of ground represented in the various collections. Canna and Muck are islands which are farmed and the influence of sheep may be felt. On these islands, and in Kilmorey Bay, collections were made on sandy ground near the shore; for the rest, most of the collecting was done in bogs or on exposed rocks. With the exception of the collections by the Glasgow excursions, no woodland habitats are represented. Basic rocks, of a friable nature, occur on Barkeval, Fionchra, Ruinsival and Bloodstone Hill, on Rhum and near Cleadale, Eigg: these undoubtedly influence the moss flora, as compared with the acid rocks of Mullach Mor on Rhum, or of

the Island of Soay. In two localities, the Sgurr of Eigg and Fionchra, perpendicular north exposures, with trickling water, gave extraordinarily rich collections of Bryophytes.

In spite of the very casual nature of the collecting, the richness of the flora combined with the co-operation of a number of helpers, has enabled us to present a fairly long list of species for these islands. We hope that the list, besides forming a basis for future work, may prove sufficiently detailed to give a general idea of the Bryophyte flora of the area.

HEPATICÆ.

MARCHANTIALES.

Reboulia hemisphærica (L.) Raddi.
Barkeval, Rhum, also Muck. No doubt much commoner than this suggests.

Conocephalum conicum (L.) Dum.
Fionchra, Rhum; Canna (G); Muck. Not however common, as in V.C. 67.

Preissia quadrata (Scop.) Nees.
Loch Scresort, Glen Kinloch and Kilmorey Dunes on Rhum; also on Canna (G).

JUNGERMANNIALES.

Aneura pinguis (L.) Dum.
Fionchra and Barkeval, Rhum; also from the machar on Muck.

A. multifida (L.) Dum.
Canna, on moist peaty soil (G).

Metzgeria furcata (L.) Dum.
Occurs in fair quantity on Fionchra and Barkeval, Rhum; Canna and Sanday (G); Cleadale and the Sgurr, Eigg; Muck.

M. conjugata Lindb.
Fionchra, Rhum.

Pellia epiphylla (L.) Corda.
This was, as usual, extremely common on the sides of streams. Collected on Rhum, Canna (G) and Muck.

P. Fabbroniana Raddi.
Barkeval on Rhum; also Muck.

Blasia pusilla L.
Kilmorey Glen, Rhum.

Gymnomitrium obtusum (Lindb.) Pears.
Fionchra, Rhum.

Marsupella emarginata (Ehrh.) Dum.
Kilmorey Glen, Rhum.

M. aquatica (Lindenb.) Schiffn.
Soay.

Alicularia compressa (Hook.) Nees.
Mullach Mor, on the Torridonian sandstone of Rhum.

A. scalaris (Schrad.) Corda.
Kilmorey Glen, Rhum; the Sgurr of Eigg.

Eucalyx obovatus (Nees) Breidl.
Sgurr of Eigg.

Aplozia crenulata (Sm.) Dum.
Stream side, Canna (G).

†**A. sphærocarpa** (Hook.) Dum.
Damp soil on Canna (G).
†**A. cordifolia** (Hook.) Dum.
Kilmorey Glen, and (M) Rhum; Canna (G).
Gymnocolea inflata (Huds.) Dum.
Mullach Mor, Rhum.
Lophozia ventricosa (Dicks.) Dum.
Mullach Mor and Loch Scresort, Rhum; also Soay.
L. incisa (Schrad.) Dum.
Sgurr of Eigg.
***Sphenolobus minutus** (Crantz) Steph.
Only a very little, mixed up with larger Hepatics, from the Sgurr of Eigg.
Plagiochila asplenoides (L.) Dum.
Canna and Sanday (G); also Muck. Var. *minor* Lindenb. occurs on Canna (G).
P. spinulosa (Dicks.) Dum.
Fionchra and Mullach Mor, Rhum; Cleadale and the Sgurr, Eigg.
Leptoscyphus Taylori (Hook.) Mitt.
Only collected on Soay.
†**Lophocolea bidentata** (L.) Dum.
Canna and Sanday (G).
†**L. cuspidata** Limpr.
Rhum (M); Hyskeir.
Chiloscyphus polyanthus (L.) Corda.
Canna (G); Cleadale, Eigg. †Var. *rivularis* (Schrad) Nees was recorded for Canna (G).
Saccogyna viticulosa (Sm.) Dum.
Mullach Mor and Fionchra, Rhum; Canna and Sanday (G); also Muck.
Cephalozia biscuspidata (L.) Dum.
Mullach Mor, Rhum; also on Soay.
†**C. media** Lindb.
Rhum (M).
Cephaloziella Starkii (Funck) Schiffn.
Mullach Mor, Rhum.
†**C. striatula** (Jens.) Douin.
A rare liverwort recorded by Mr. Marquand for Rhum.
Odontoschisma Sphagni (Dicks.) Dum.
Mullach Mor, Rhum.
†**O. elongatum** (Lindb.) Evans.
Another rare form discovered by Mr. Marquand on Rhum.
Calypogeia Trichomanis (L.) Corda.
Loch Scresort and Mullach Mor, Rhum; also on Canna (G).
C. fissa (L.) Raddi.
Barkeval, Rhum; Canna (G).
Bazzania tricrenata (Wahl.) Pears.
Sgurr of Eigg.
Lepidozia reptans (L.) Dum.
Soay.
L. setacea (Web.) Mitt.
Sgurr of Eigg; Soay.
Blepharostoma trichophyllum (L.) Dum.
Loch Scresort, Rhum.
***Herberta adunca** (Dicks.) Gray.
In the mossy curtains on the north side of Fionchra, Rhum. A rare liverwort only found in one area, Snowdon, outside Scotland.

H. Hutchinsiæ (Gottsche) Evans.
The brick red tufts of this, only slightly less rare species, were readily picked out among the other Bryophytes of Fionchra on Rhum and of the Sgurr of Eigg.

Mastigophora Woodsii (Hook.) Nees.
Another rare Hepatic of the Mountains of Scotland, often found with *Herberta,* but here in a different locality; on Barkeval, Rhum.

Diplophyllum albicans (L.) Dum.
This very common species was widely distributed on the islands, except that we had no specimens from Muck and Hyskeir.

Scapania gracilis (Lindb.) Kaal.
Loch Scresort, Rhum; Canna (G).

S. dentata Dum.
Fionchra and Mullach Mor, Rhum; also Soay.

S. undulata (L.) Dum.
Muck.

Radula complanata (L.) Dum.
From deciduous woodland on Canna (G).

†**R. Lindbergiana** Gottsche.
Recorded for Rhum by Mr. Marquand.

Pleurozia purpurea (Lightf.) Lindb.
Kilmorey Glen and Fionchra, Rhum; the Sgurr of Eigg. This conspicuous, purplish-red, liverwort was not so common here as it is on the Isle of Raasay.

***Madotheca Thuja** (Dicks.) Dum.
This uncommon Hepatic turned up in Mr. White's collection from the pitchstone island of Hyskeir, and is new to V.C. 104.

Lejeunia cavifolia (Ehrh.) Lindb.
Mullach Mor, Barkeval and Fionchra, Rhum; Sanday; Cleadale, Eigg.

L. patens Lindb.
Sgurr of Eigg.

Frullania Tamarisci (L.) Dum.
This occurred commonly on all the islands investigated.

F. dilatata (L.) Dum.
Canna (G).

MUSCI.

SPHAGNALES.

Sphagnum rubellum Wils.
Mullach Mor and Barkeval, Rhum; also on Soay.

S. acutifolium Ehrh.
Mullach Mor and Fionchra, Rhum; Canna (G); Cleadale and the Sgurr, Eigg; also Soay.

S. plumulosum Röll.
Common. On Rhum, Canna (G), Eigg, Muck and Soay.

†**S. compactum** D.C.
Var. *subsquarrosum* Warnst. Canna (G) was found on Barkeval, Rhum.

***S. strictum** Sull.
Kilmorey Glen, Rhum. This extremely rare moss, detected first in Perth in 1925, has not been found before in the Scottish Islands.

S. amblyphyllum Russ.
Var. *mesophyllum* Warnst. Soay.

S. recurvum P. de Beauv. o
Type and var. *majus.* Angst. occurred in Soay peat and †var. *parvulum* Warnst. on Canna (G).

S. cuspidatum Ehrh.
Var. *falcatum* Russ. Mullach Mor, Rhum; the Sgurr of Eigg; Soay.
*Var. *plumosum* Bryol. germ. Mullach Mor, Rhum; Soay.

S. molluscum Bruch.
Eigg, below the Sgurr; Muck; in peat on Soay.

***S. obesum** Wils.
Kilmorey Glen and Barkeval, Rhum; also on Soay.

S. subsecundum Nees.
Kilmorey, Rhum.

***S. inundatum** Russ.
Rhum, Kilmorey Glen and in the peat on Bloodstone Hill.

S. auriculatum Schp.
Barkeval, Rhum; Canna (G); in the peat on Soay.

S. crassicladum Warnst.
Below the Sgurr of Eigg. This was first recorded for V.C. 104. from Loch Coruisk, Skye (E.M.L.)
*Var. *magnificum* Warnst. Mullach Mor, Rhum.

S. papillosum Lindb.
Canna (G); and var. *normale* Warnst. Mullach Mor, Rhum.

S. cymbifolium Ehrh.
Kilmorey and Loch Scresort, Rhum; Muck; and, on Soay, both living and in peat.

BRYALES.

†**Tetraphis pellucida** Hedw.
Rhum (M).

Catharinea undulata Web. and Mohr.
Canna (G).

Oligotrichum hercynicum Lam.
Bare places among rocks on Barkeval, Rhum and on the Sgurr of Eigg.

Polytricum aloides Hedw.
Edge of the sand dunes Kilmorey Bay, Rhum; and Cleadale, Eigg.

P. alpinum L.
Uncommon. Found once below the Sgurr of Eigg.

P. piliferum Schreb.
Kilmorey Bay, Rhum; Canna (G); and Cleadale, Eigg.

†**P. juniperinum** Willd.
Mullach Mor, also (M), Rhum; Cleadale and the Sgurr, Eigg.

P. formosum Hedw.
Canna (G).

P. commune L.
Common on damp moorland as usual. Rhum, Canna, Muck and Soay.

Diphyscium foliosum Mohr.
Occasionally in small patches on Fionchra and in Glen Kinloch, Rhum.

Ditrichum homomallum Hampe.
On the sand dunes Kilmorey Bay and on Barkeval, Rhum.

†**D. flexicaule** Hampe.
Rhum (M).

Ceratodon purpureus Brid.
Common on bare places. Rhum, Eigg, Muck and Hyskeir.

***Rhabdoweisia fugax** B. and S.
In small quantity on the Sgurr of Eigg.

Dichodontium pellucidum Schp.
Kilmorey Glen and Fionchra, Rhum; Cleadale, Eigg.

†**Dicranella heteromalla** Schp.
Kilmorey Bay and Loch Scresort, Rhum; also on Canna (G).
D. squarrosa Schp.
Fionchra and Barkeval, Rhum.
Blindia acuta B. and S.
Fionchra, Rhum; Cleadale and the Sgurr, Eigg.
†**Dicranoweisia cirrata** Lindb.
Kilmorey Glen and (M), Rhum.
Campylopus flexuosus Brid.
Mullach Mor, Rhum; Canna (G), also Soay.
C. pyriformis Brid.
Cleadale, Eigg.
C. fragilis B. and S.
Canna and Sanday (G); Cleadale and the Sgurr, Eigg.
C. atrovirens De Not.
Not uncommon. Kilmorey etc., Rhum; Canna (G); Cleadale and the Sgurr, Eigg.
C. brevipilus B. and S.
Canna (G).
Dicranodontium longirostre B. and S.
The Sgurr of Eigg.
Dicranum Bonjeani De Not.
Muck.
D. scoparium Hedw.
Canna (G), Cleadale and the Sgurr, Eigg; also Muck.
Var. *orthophyllum* Canna (G).
D. majus Turn.
Cleadale, Eigg.
†**D. fuscescens** Turn.
Mullach Mor and (M), Rhum.
†**D. Scottianum** Turn.
Rhum (M).
Leucobryum glaucum Schp.
Fionchra, Rhum; also Canna (G).
Fissidens bryoides Hedw.
Canna (G).
†**F. osmundoides** Hedw.
Fionchra and (M), Rhum.
F. adiantoides Hedw.
Muck.
†**F. decipiens** De Not.
Rhum (M).
†**F. taxifolius** Hedw.
Rhum (M), Canna (G) and Muck.
Grimmia apocarpa Hedw.
Var. *rivularis* W. and M. Canna (G).
†**G. maritima** Smith.
Rhum (M), Sanday (G) and Muck.
G. pulvinata Smith.
Cleadale, Eigg.
G. trichophylla Grev.
Muck.
Rhacomitrium aciculare Brid.
Canna (G); Cleadale, Eigg.
R. fasciculare Brid.
Bloodstone Hill, Barkeval and Fionchra, Rhum; Canna (G); Cleadale, Eigg.
R. heterostichum Brid.
Kilmorey, Rhum; also Canna (G).

R. lanuginosum Brid.
Very common on all the islands. Peat formed from it found on Rhum.

Ptychomitrium polyphyllum Fuern.
Loch Scresort, Rhum; Canna (G); Cleadale, Eigg; Muck.

Hedwigia ciliata Ehrh.
Muck.

Tortula muralis Hedw.
Muck.

T. subulata Hedw.
Fionchra, Rhum.

†**T. ruraliformis** Dixon.
Sanday (G) and Muck.

Barbula rubella Lindb.
Muck. On sandy ground.

***B. tophacea** Mitt.
Muck.

B. rigidula Mitt.
Muck.

B. revoluta Brid.
Cleadale, Eigg.

†**B. convoluta** Hedw.
From rich pasture on Sanday (G).

†**B. unguiculata** Hedw.
On Sanday with the above (G).

Weisia rupestris C.M.
On the South face of Fionchra, Rhum.

W. verticillata Brid.
Muck. This was first recorded for V.C. 104 from Raasay (K.B.B.)

***Trichostomum crispulum** Bruch.
Muck.

†**T. mutabile** Bruch.
S. Fionchra, Rhum; Canna and Sanday (G); also Muck.
†Var. *littorale* Dixon and type, recorded as new for V.C. 104 by Mr. Marquand.

†**T. tortuosum** Dixon.
S. side of Fionchra and (M), Rhum; Cleadale, Eigg.

Encalyptra ciliata Hoffm.
On the mugearite of Fionchra, Rhum.

Anœctangium compactum Schwaeg.
Fionchra, Rhum.

Zygodon Mougeotii B. and S.
Canna and Sanday (G); the Sgurr of Eigg; also Muck.

Ulota crispa Brid.
Canna (G); Cleadale, Eigg.

U. phyllantha Brid.
Canna (G).

***Oedipodium Griffithsianum** Schwaeg.
Only one small patch of this rare moss was found, on a ledge at about 1000 ft., on the Sgurr of Eigg.

Splachnum sphæricum Linn. fil.
After much searching, a very little of this was found on deer-dung, on Mullach Mor, Rhum.

†**Funaria ericetorum** Dixon.
Rhum (M).

F. Templetoni Sm.
Canna (G) and Muck.

F. hygrometrica Sibth.
Canna and Sanday (G); also Muck.

***Aulacomnium turgidum** Schwaeg.
This extremely rare moss was among the collection from Cleadale, Eigg.
A. palustre Schwaeg.
Soay.
†**Bartramia pomiformis** Hedw.
Fionchra, Bloodstone Hill and (M), Rhum; also on the Sgurr of Eigg.
Philonotis fontana Brid.
Probably quite common, but only collected from Fionchra, Rhum; Canna (G); Muck; Soay. Also in peat on Soay.
Breutelia arcuata Schp.
Barkeval and Ruinsival, Rhum; Cleadale and the Sgurr, Eigg; Muck; Soay.
***Webera acuminata** Schp.
Fionchra, Rhum.
W. nutans Hedw.
Also only from Fionchra, but no doubt much commoner than this suggests.
†**W. albicans** Schp.
Rhum (M).
Bryum filiforme Dicks.
Fionchra, Rhum; Cleadale, Eigg.
†**B. pallens** Sw.
Barkeval and Kilmorey, Rhum; Sanday (G); Muck.
B. pseudo-triquetrum Schwaeg.
Fionchra and Mullach Mor, Rhum; Canna (G); also Cleadale, Eigg.
B. cæspiticium L.
Muck.
B. capillare L.
Sanday and Canna (G); Cleadale, Eigg; Muck.
B. alpinum Huds.
Fionchra, Rhum; Cleadale, Eigg.
B. argenteum L.
Barkeval, Rhum.
Mnium undulatum L.
Fionchra, Rhum; Sanday (G); Muck; Hyskeir.
M. hornum L.
Mullach Mor and Fionchra, Rhum; Canna and Sanday (G); Muck; Hyskeir.
M. punctatum L.
Fionchra and Mullach Mor, Rhum; Canna (G).
Fontinalis antipyretica L.
Soay and Canna (G).
Pterygophyllum lucens Brid.
Mullach Mor, Rhum; Canna (G); Soay.
Pterogonium gracile Schwartz.
Fionchra, Rhum.
Antitrichia curtipendula Brid.
Fionchra, Rhum.
†**Heterocladium heteropterum** B. and S.
Barkeval and (M), Rhum; on Soay
Thuidium tamariscinum B. and S.
Common, Rhum; Canna and Sanday (G); Eigg; Soay.
T. delicatulum Mitt.
Cleadale, Eigg.
Myurium Hebridarum Schp.
Rock faces on Sanday, also found by (G). This moss is only found in V.Cs. 97, 103, 104 and 110, the Canary Isles and the Azores.

Camptothecium sericeum Kindb.
Sanday (G); the Sgurr of Eigg; Hyskeir.
C. lutescens B. and S.
Muck.
Brachythecium albicans B. and S.
Sanday (G).
†**B. salebrosum** B. and S.
Sanday (G).
B. rutabulum B. and S.
Fionchra, Rhum; Canna and Sanday (G); also Muck.
†**B. plumosum** B. and S.
Rhum (M).
B. purum Dixon.
Canna and Sanday (G); Cleadale, Eigg.
Hyocomium flagellare B. and S.
Barkeval, Rhum.
Eurhynchium prælongum Hobk.
Canna and Sanday (G); Sgurr of Eigg; Muck; also Hyskeir.
†**E. pumilum** Schp.
Rhum (M).
†**E. tenellum** Milde.
Canna (G).
E. myosuroides Schp.
Fionchra and Ruinsival, Rhum; Canna and Sanday (G); Muck.
†**E. striatum** B. and S.
The wet N. side of Fionchra, Rhum; and at Cleadale, Eigg.
E. rusciforme Milde.
Barkeval, Rhum; also Canna (G).
Plagiothecium elegans Sull.
Barkeval, Rhum.
†**P. denticulatum** B. and S.
Mullach Mor and (M), Rhum; Canna (D).
P. undulatum B. and S.
Mullach Mor, Rhum; Canna (G); also Cleadale, Eigg.
Amblystegium serpens B. and S.
Kilmorey, Rhum; Sanday (G).
A. filicinum De Not.
Canna and Sanday (G); also Muck.
Var. *protensum* Canna (G).
†**Hypnum stellatum** Schreb.
Mullach Mor and (M), Rhum; Canna (G); Muck.
Var. *protensum* Roehl Canna (G).
†**H. fluitans** L.
Mullach Mor, Rhum; Canna (G); Soay; Hyskeir.
H. revolvens Swartz.
Barkeval, Kilmorey Bay and Fionchra, Rhum; Canna (G); Cleadale, Eigg; Muck.
†**H. intermedium** Lindb.
Canna (G).
H. commutatum Hedw.
N. side of Fionchra, Rhum.
†**H. falcatum** Brid.
Rhum (M).
H. cupressiforme L.
Common throughout the islands. Var. *ericetorum* B. and S. on Barkeval and on Mullach Mor, Rhum.
†**H. callichroum** Brid.
Rhum (M).

H. molluscum Hedw.
Fionchra, Rhum; Canna (G); Muck.
†Var. *condensatum* Schp. Rhum (M).
†**H. scorpiodes** L.
Barkeval, Kilmorey and (M), Rhum; also Canna (G).
***H. stramineum** Dicks.
Cleadale, Eigg.
H. sarmentosum Wahl.
Canna (G).
H. cuspidatum L.
Fionchra, Rhum; Canna and Sanday (G); Cleadale, Eigg; Muck; Hyskeir.
H. Schreberi Willd.
Fionchra, Rhum; Canna (G); Cleadale, Eigg; Muck.
Hylocomium splendens B. and S.
Fionchra, Rhum; Canna and Sanday (G); Cleadale, Eigg; Muck; Soay.
H. loreum B. and S.
Fionchra, Rhum; Canna (G); Sgurr of Eigg; Muck; Soay.
H. squarrosum B. and S.
Sanday and Canna (G); Cleadale, Eigg; also Hyskeir.
H. triquetrum B. and S.
Fionchra, Rhum; Cleadale, Eigg.

AGRICULTURAL PROGRESS AND AGRICULTURAL DEPRESSION DURING THE LAST SIXTY YEARS.

by

SIR DANIEL HALL, K.C.B., LL.D., D.SC., F.R.S.

As a student of science I can look back for sixty years, during which period nearly the whole of what we now recognise as the science of agriculture has grown up or at least has been reconstituted. It is true that earlier in the nineteenth century the great foundations of knowledge of the nutrition of the plant and the animal had been laid. Building upon the earlier work of Priestley and Lavoisier, of Bonnet and de Saussure, Liebig, Boussingault and Gilbert had demonstrated that the crop draws the mass of its material from the air, but that small quantities of other elements—in particular combined nitrogen, phosphoric acid and potash—have to be supplied by the soil. The Rothamsted experiments had laid down the basis of rational manuring and artificial fertilisers had taken their place in the practice of agriculture. At the same time Voit and others had established the broad principles of animal nutrition; had distinguished between energy supply and tissue repair, had evaluated the part played by carbohydrates, fat and proteins in the former, and set out the requirements of animals for proteins to satisfy the latter need. Coefficients for digestibility had also been determined, so that in both directions science had supplied a very fair explanation of good agricultural practice.

But one great field of knowledge was still unexplored. As a schoolboy I had the occasional opportunity of hearing the popular lectures given by the leaders of science of the day under the auspices of the Gilchrist Trust, and thus I heard Tyndall and Dallinger tell of their experiments which followed up Pasteur's discovery of the actions of bacteria. I learned how the fermentation and putrefaction of liquids like meat broth or hay infusion were due to living organisms introduced by the dust of

the air and the dirt adhering to the vessels. These organisms were destroyed by heat; thus the liquid liable to apparently spontaneous decomposition could be sterilised by heat and if sealed up in its container while still boiling would remain unchanged for an indefinite period. If air was admitted from the higher regions of the atmosphere where the dust did not reach, as when the sealed vessels part full of the sterilised medium were opened well above the snow line of the Alps, or if the admitted air had first been filtered through layers of cotton wool that would hold back the dust particles, the liquid still remained sterile. It was not air that caused putrefaction but a living agency so minute as to be floating about almost universally. Tyndall did the experiments in the Alps; Dallinger for patient hours had watched under the microscope the multiplication of the organisms themselves. While the bacteria were killed at a temperature of boiling water, cold slowed down their action, which was practically inhibited at freezing point. Out of these investigations grew the modern methods of food preservation, which became of great significance to agriculture. Importation of meat in tins from America and Australia began to become noticeable about 1880, refrigeration came later about 1890. Pasteur had shown that these micro-organisms generated disorders in wine and beer and were the cause of a disease of silkworms, and it was not very long before investigators began to look for their effects in matters agricultural. Schloesing and Müntz (1877) in Paris turned their attention to the classical process of obtaining nitre from soils which were rich in organic matter or had absorbed urine. It was in this way that the nitre required for gunpowder had for ages been produced, and as warmth, moisture and time were essential, action akin to Pasteur's bacteria was suggested. Schloesing and Müntz found that the production of nitrates would cease if the soil mass was heated to the temperature of boiling water, and that it could be suspended by the presence of chloroform or antiseptics. Ammonium salts in weak solutions would be converted into nitrates if they were

infected with a little fresh soil, but there would be no change if the solution was boiled after the addition of the soil. If a drop of the solution from an actively nitrifying medium were added to a sterile solution containing ammonium salts, it at once started up nitrification. Evidently the chemical change from ammonia to nitrates was due to a *contagium vivum,* but it was not until some years later that Winogradsky in 1895 invented an elegant technique by which he isolated and described the organisms concerned.

In 1886 came the publication of a fundamental discovery by two German investigators—Hellriegel and Wilfarth. The source of nitrogen in vegetation had been a problem ever since the beginnings of science. Can the plant make the use of the nitrogen of the atmosphere in which it lives, or must it draw this essential from soil or manure? Liebig had appealed to the small trace of ammonia always contained in the air, but Gilbert showed how insufficient this source was for the needs of a crop, and again by an elaborate series of experiments demonstrated that plants of various species at the end of their growth contained no more nitrogen than had been present in the seed and the fertiliser supplied to the sand in which they were grown, a thesis which was confirmed on a large scale by the field experiments at Rothamsted.

But however impregnable the evidence that was thus accumulated, there remained a residuum of unexplained fact which was always occupying Gilbert's mind. When balance sheets were drawn up comparing the nitrogen removed in the crops of a rotation against the amount supplied in the manure, together with the gain or loss to the soil as determined by analysis, there was always a surplus of nitrogen, which became larger the more crops like clover or lucerne figured in the rotation. Now Hellriegel and Wilfarth found that though clover growing in plots of sand took no nitrogen from the atmosphere, as in Gilbert's experiment, yet on occasion it would begin to grow freely though no nitrogen compounds had been supplied. Such plants were found to have their roots

studded with little nodules containing bacteria, and similar nodules were always found on the roots of clover and allied leguminous plants taken from the field or garden. To summarise a long story, leguminous plants habitually live in symbiosis with a particular bacterium which 'fixes' or brings into combination the free nitrogen of the atmosphere. The host plant supplies the carbohydrate from which the bacteria derive the energy required to bring nitrogen gas into combination; in return the bacteria hand on to the host plant the combined nitrogen it requires. Thus was at once revealed a source of that stock of combined nitrogen in the world upon which all living organisms depend. The long standing discrepancy in the balance sheets of rotations was accounted for, indeed the Rothamsted experiments alone provided ample evidence to corroborate Hellriegel's conclusions from the laboratory. Again it became possible to understand how the soils of old civilised countries like Europe, India or China show no exhaustion after hundreds or thousands of years of continuous cultivation and removal of crops, because the rotations practised always included a leguminous crop.

Some years later in 1901 the story was amplified by Beijerinck's discovery of another organism, *Azotobacter*, which lives free in the soil and is independent of symbiosis. It obtains from decaying vegetable matter the energy needed to fix relatively large amounts of nitrogen. Sufficient importance has not perhaps been accorded to this organism, as the chief source of the accumulation of nitrogen in virgin soils. At Rothamsted I found that two plots of land which had been allowed to run wild for over 20 years, so that the natural vegetation fell back to the soil, had been gaining nitrogen at the rate of upwards of 100 lbs. per annum, chiefly through the agency of *Azotobacter*. This organism was also identified in virgin soils taken from every quarter of the globe.

The threat that our cultivated soils would wear out was thus allayed, though the consequences of Hellriegel's experiments were still so little appreciated that Crookes in his address to the British Association in 1898 warned the

world of ultimate famine, because nitrogen compounds were always being destroyed by burning etc. Man could only make up for such losses if some workable process could be discovered for bringing nitrogen into combination by the electric discharge.

However unfounded Crookes' threat was, inventors were at work on the lines he suggested and before the war a hydro-electric company in Norway, by blowing air through an electric arc, was manufacturing calcium nitrate in competition with the natural sodium nitrate from Chile. About the beginning of this century also the process of making Cyanamide by combining atmospheric nitrogen with calcium carbide was discovered, nowadays one of the more important fertilisers. The War called for immense quantities of nitrogen compounds, since they are the basis of all explosives, and it saw the perfecting of a superior process devised by Haber, whereby nitrogen and hydrogen were brought into combination as ammonia, which could then be oxidised to nitric acid. It was Haber's process alone which enabled Germany to maintain her supplies of ammunition through the long war. Since that time the Haber and other processes have been enormously developed in all countries in anticipation of war, but immediately for the manufacture of fertilisers. In 1913 the consumption of combined nitrogen from all sources—ammonia from the gas works, Chile nitrate of soda and synthetic compounds—amounted to 727 thousand tons of which 51 thousand had been synthetically produced; in 1937 the consumption of synthetic compounds alone had risen to 2,168 thousand tons, the contributions from the older sources remained much as they were—712 thousand tons. Of the other fertilisers, the last sixty years have seen the great development of the phosphate deposits of Tunis and Algeria, as also the discovery of basic slag. The iron ores of N. Yorkshire contain notable amounts of phosphorus, and on smelting the resulting pig iron is so rich in that element as to be unfit for conversion into steel. Thomas and Gilchrist of Middlesbrough discovered (1878) that if lime and magnesia are added to the Bessemer

converter the phosphorus becomes oxidised and combines with the bases, leaving the resulting steel free from the phosphorus, which has formed a basic phosphate of lime in the slag. It was another north-countryman, Wrightson, who showed that this phosphate needed no treatment with acid but became an effective fertiliser for grassland when finely ground. When Somerville came to Newcastle his experiments at Cockle Park brought home to farmers what an immense improvement they could effect in the stock feeding capacity of their poorer grassland by means of basic slag, and when a little later Douglas Gilchrist had demonstrated the virtues of wild white clover in gathering nitrogen, the foundations were laid for the system of alternate husbandry with long leys which promises to be as important for British farming as was the four-course rotation in its day.

The same period has seen the development of the Stassfurt Potash Deposits, and since the war of the parallel deposits in Alsace. The only other extensive deposit known is that in Spain, largely in German control and still undeveloped. Of course the Dead Sea is now yielding commercial potash, but whether it can compete on anything like equal terms with the German and French mines has yet to be proved.

The necessity of abundant potash fertiliser to all kinds of fruit trees, especially apples, has been demonstrated since the war by the work of Wallace at Long Ashton. By this means the extent of land suitable for fruit growing has been greatly enlarged, and it has become possible to grow an apple like Cox's Orange Pippin on a commercial scale.

Time does not permit me even to allude to much other work concerning the soil and fertilisers: such as the discovery that the partial sterilisation of soil would enhance its fertility, a process now almost universally employed by cultivators under glass.

I must pass on, however hastily, to one of the revolutionary discoveries—the bringing to light about the beginning of this century of Mendel's generalisations

concerning heredity in plants. Thus late came into being the science of genetics. At once it gave the plant breeder a technique, not so much constructive perhaps as critical. It is true that the old empirical methods of the plant breeder still hold; he must breed, and the larger the scale on which he works the more chance he has of finding a favourable combination or a new mutation of value. Strength still lies in big battalions, but science teaches him how to fix his successes, if they can be fixed; it may give him the odds against attaining his desideratum, and it has shown the futility of volumes of attempts to improve cereals by mass selection. It has established the difference between fluctuations in individuals due to environment and genetic mutations; it has shown how ' mutations ' occur as sudden jumps of some magnitude and are inherited; it is finding means of increasing the frequency of mutations. Practical improvement came first with cereals, because they are normally self-fertilised and relatively stable pure lines can be established quickly. Biffen's Yeoman wheat, Beaven's Plumage Archer and Hunter's Spratt-Archer barleys in this country, Victory oat from Svalöf, Juliana wheat from Holland, and Marquis wheat in Canada, are instances of the application of the new methods to cereal breeding; but in western Europe the advances are limited by the high degree of productivity to which the old varieties had already been raised by centuries of empirical selection. Work however with plants habitually cross-fertilised is less advanced by reason of the technical difficulties of maintaining pure lines. As is well known, the sugar content of sugar beet has been doubled by scientifically controlled methods of selection alone, but the yield of sugar per acre has advanced but little and many desirable features in the plant have been ignored. Far otherwise has been the case with its great rival—the sugar cane. The Dutch investigators in Java, by crossing existing varieties with a wild species of cane, introduced certain factors of disease resistance into their seedlings which has resulted in varieties that have well nigh doubled the yield of sugar per acre. In 1926 for example, the estimated

yields were Java 15 tons per hectare, Cuba 4.5, Hawaii 7.5, India less than 3, while the best yield from sugar beet (Holland) is at present about 5½ tons of sugar per hectare.

I can touch but briefly on some of the results achieved by the plant breeders, such as the establishment of a range of potato varieties immune to Wart Disease *(Synchytrium endobioticum)*, of apple stocks immune to the attacks of woolly aphis (Crane etc.), of varieties of our native grasses of a more leafy character and a more perennial habit (Stapledon and his colleagues at Aberystwyth).

The science of genetics took a great step forward when Morgan and his school, following up the earlier suggestions of Weismann and Boveri, associated the unit characters postulated by Mendel with particular chromosomes visible at certain stages in the cell nucleus. At once the generalisations established by experimental breeding in animal and plant were supplied with a material basis; it began to be possible to account for many of the observations which had not been explainable on the bare mendelian basis. Particularly has this been so since the discovery of polyploidy—the duplication or even higher repetition, within the cells of a new variety, of the set of chromosomes carried by the normal species. So results a relatively giant cell, reflected in many cases by increased size in the whole plant. Wheat and oats, plums, apples and pears, are such polyploids which have occurred accidentally and have established themselves in virtue of their extra vigour. Such ' jump ' changes in the structure, arrangement or number of the chromosomes—mutations—have been verified experimentally; they form the raw material, the basis of variation, for the theory of evolution, replacing in it Darwin's conception of progressive change by the accumulation of infinitesimal variations. I have perhaps given too much of my scanty time to this aspect of science, but it affords a striking example of the manner in which pure scientific research may suddenly become of immense economic importance. A quarter of a century ago the study of the inner mechanism of the nucleus, now known as the science of cytology, was of interest only to a

few research workers scattered about the world; now it has become an essential tool in the hands of the plant breeder, a tool whose practical value is fully proved.

The protection of plants against disease has been entirely developed within the last sixty years. Bordeaux mixture was invented about 1885 to control the mildew (oidium) of vines, its effectiveness became so manifest that its use is now universal. In the south of France and in Italy you will see the walls of every cottage stained with copper green from the spray that has been applied to the vines growing there. Bordeaux mixture was soon found to protect potatoes from the blight; in one form or another it is now one of the general fungicides. The gardener had found that soapy water was useful to deal with greenfly; by the early nineties the hop growers were regularly spraying with soft soap and quassia against the aphis which in a bad season would reduce a crop to a fraction of its normal yield. Fruit growers were beginning to use the same spray against the leaf-curling aphis of apples and plums. Sulphur, first as powder and then in solution as a fungicide, and the arsenicals against caterpillars, were coming into use.

These empirical remedies were followed by studies of the life histories of the insect pests and the course of development of the fungi, so as to ascertain the most effective time of attack. The chemists looked for new killing materials and drew upon the resources of physical chemistry to introduce into the spray fluids substances which would increase their power of wetting, spreading and sticking. The geneticist is apt to intervene and affirm that the only cheap and final cure is the breeding of varieties that are immune to the prevailing disease. He is liable to be countered by an answering adaptation of the parasitic organism. Thus investigators have succeeded in raising potatoes immune to the ordinary forms of blight by crossing with species derived from S. America, the original source of the potato, only to find the *Peronospora* evolve a new mutation which can penetrate the new armour.

So the spraying technique, costly though it may be, is not likely to be displaced.

Of recent years forms of infection have come to light which if not new—for some of them were described a century or more ago—were unrecognised before, but have now become a widespread and increasing menace. These are the ultra-microscopic viruses, which in animals are responsible for such disorders as foot and mouth disease and dog distemper, and in man smallpox and scarlet fever. With animals immunisation can often be effected, but a corresponding protection is impracticable with plants, nor is any other treatment, like spraying, effective. Unfortunately virus diseases do not necessarily kill; in many cases infected plants will live on, with diminished vitality but still a source of infection, for they never free themselves from the disease. Potatoes afford the best known example of a virus disease. It has long been recognised that they are liable to an affection that causes the leaves to curl and to become mottled or mosaic, with a great falling-off in yield. Towards the end of the last century potato growers found that seed from Forfarshire and other northerly districts in Scotland would yield a healthy crop, into which however the disease would gradually spread, until about the third or fourth year a fresh stock would have to be procured from Scotland if a commercial yield was to be obtained. Investigation has now shown that the potato is subject to the attack of several distinct viruses which are communicated from plant to plant by species of aphis, and since the potato is propagated vegetatively by small tubers, not seed in the proper sense of the term, the disease is carried on from one season to the next. In the Scottish districts growing potatoes for seed, as in other elevated districts North Wales, Cumberland, Dartmoor—the aphis carriers are rare, consequently a field of potatoes that has been 'rogued' of individuals evidently affected will yield seed of a high degree of freedom from virus.

Turning now to live stock, the most striking advances of science have been made in connection with disease.

When I was an undergraduate at Oxford a young zoologist there, A. P. Thomas, was engaged in tracing the life history of the liver fluke of sheep, which in the wet years about 1879 had been causing exceptional losses in the flocks of Great Britain. Thomas discovered that the organism has to pass one stage of its life in a water-snail which lives on the damp meadows and is picked up by the sheep during grazing. In the sheep the organism develops into the fluke, which later produces eggs that are excreted on to the grass. There they hatch into minute free-swimming forms which enter snails again and the cycle is resumed. This was about the first example to be discovered of a parasite which requires two distinct hosts to complete its life cycle. It is an interesting example of the way in which science progresses that a German investigator, Leuckart, simultaneously traced the same life history. Both published their independent conclusions in October 1882. Later a number of similar cases became known—malaria where the secondary host, the carrier, is a species of mosquito; and the whole range of trypanosome diseases—ngani and sleeping sickness, in which the parasite passes through three hosts, one of the larger animals like cattle, and a species of biting fly that transmits it to human beings.

But the most immediate advances arose out of Pasteur's work; medical research all the world over became occupied with the investigation of bacterial diseases and the means of conferring resistance on the human being or animal affected. I have neither the time nor the qualifications to deal with the subject. It is the whole history of the development of preventive medicine, in which at once it became apparent that human and veterinary medicine are one, for in so many of the epizootic diseases men and animals participate. I need only mention anthrax, the bacterial nature of which was among the first to be recognised by Pasteur, and Koch's memorable investigations of the tubercular bacillus in its three forms—human, bovine and avian. Indeed the control of bovine tuberculosis remains one of the most pressing questions of the

day both for public health and for agriculture.

Of the virus diseases, the nature of which has only been recognised within the present century, I can say little. But the investigation of foot and mouth disease, taken up in this country in 1924, has already cost upwards of £200,000 without as yet yielding any certain method of immunisation. It may seem a large sum of money, but until a trustworthy preventive method can be discovered the slaughter of contacts remains the only safeguard against the spread of this wasteful disease from any of the sporadic invasions to which this country is subject, and compensation alone over the 1923-24 outbreak amounted to over three million pounds.

As I have already indicated, the basic principles of animal nutrition had been laid down before the period with which I am dealing, but the broad evaluation of food materials as carbohydrates, fat and proteins did not embrace the whole story. Following up Emil Fisher's classical paper on the amino-acids of casein, Osborn in America began to take the vegetable proteins to pieces, since they are resolved by digestion in the animal into simpler compounds which are then reconstructed to constitute the different proteins of milk and flesh. Then in 1906 came an investigation of prime importance by Gowland Hopkins, who found that rats fed, upon a properly balanced diet but in which the protein was zein, the protein of maize, would waste away through nitrogen starvation. This condition would be rectified by the addition to the diet of a small amount of tryptophane, which shares in the composition of many proteins but proved to be absent from zein. Only with some tryptophane to enter into the complex could the other constituents of the zein molecule be utilised by the animal, as though a dwelling house could not be built if glass were not supplied with the other materials. Thus it was shown that the proteins are not all of equal value to meet the nitrogen requirements of the animal, and justification was afforded for the practical graziers'

observation that certain foodstuffs ' nick ' together in the economical feeding of this or that kind of livestock.

Gowland Hopkins, with other workers like McCollum in America showed that animals would refuse to grow or breed when fed upon a duly balanced diet of purified carbohydrate, fat and protein with the necessary mineral salts, indeed they began to show certain specific disorders which had been recognised in practice. Investigation thus led to the discovery of the various *vitamins,* complex substances derived always in the first instance from plants, which in relatively trifling quantities are essential to the utilisation by man or animals of the major constituents of diet. Wherever animals have access to grass and other green fodder they can satisfy their vitamin requirements, but when intensive feeding is practised with concentrated materials like grain or oil cakes, as in the rapid fattening of pigs and the indoor production of milk or of eggs, vitamin deficiency is liable to occur, resulting in waste of food and various nutritional disorders. These considerations also apply to human beings, especially under modern conditions where there may be a preponderance of cereals in the dietary and where the preparation of foods for the market may have removed the parts rich in vitamins. It was further found that deficiencies of essential minerals may also occur; in certain districts inferior grazing capacity of the pastures, even specific disorders, may follow the absence from the fodder, primarily of course from the soil, of iron, phosphoric acid or calcium, and the list of such deficiency diseases is still being extended.

The principles of genetics apply equally to animals as to plants, but investigation is far more difficult and has not extended so far. One complication is introduced by sex, which exerts a far greater influence over the physiology of the organism in animals than in plants. Again the domestic animals possess a relatively slow rate of reproduction, thus greatly prolonging investigation. Actually many of the chief advances in genetical theory have accrued from the investigation of *Drosophila,* a minute fruit fly, which completes its life cycle in about

11 days, and can be bred in thousands in the laboratory. Further the characters of economic importance in our domestic animals, such as speed in horses, milk production in cows, the quality of wool in sheep, egg laying capacity in fowls, though undoubtedly genetic in origin and therefore subject to inheritance, are governed by the interplay of many factors and require extended analysis before any method of control can be devised. It is easy to conceive of synthetic breeds of cattle or sheep which would combine many advantages possessed separately by existing breeds, but to realise these conceptions would involve work with thousands of animals and extending over many years. Moreover there is no prospect of an immediate pecuniary return, since monopolies or patents are not practicable in agriculture. As regards the development of scientific discovery, agriculture is at a disadvantage compared with other industries. The Mond Company may spend over a million pounds converting a laboratory discovery into a working process for the extraction of nickel from its ores, or the Badische Anilin Company an equal sum in arriving at synthetic indigo, but with success reward is assured. Agriculture can offer no possible parallels. The most illuminating application of genetics to animal breeding has been Punnett's discovery of the linkage of sex with plumage colour in certain hybrids of breeds of fowl, which enables the egg producer to cast out on hatching the relatively useless males. Punnett has even advanced from this point to a pure race of fowls which exhibits the sex distinction without any crossing.

I should have liked to have had time to recount the change in the attitude of our own Government towards agricultural research during the period. England had the distinction of establishing the first series of agricultural experiments at Rothamsted. John Lawes provided an endowment and made a public Trust of the Station in 1889, but for a long time it remained the only institution for research in Great Britain. Even when I succeeded Gilbert in 1902, Rothamsted was still dependent upon its original income of £2,700 a year, and when an appeal for assistance

was made the then President of the Board of Agriculture declared that the Government was content to utilise the information provided by research in America and Germany, countries in which agriculture was of more moment than it was in Great Britain, and that Rothamsted was to look in the future as in the past to private benefactors. Nor did the Universities make any contribution to agricultural research, though after the foundation of the Agricultural Colleges about 1892, most of which were associated with a University, some of their teachers were able to take up investigation in their limited leisure. It was not until 1910 that Mr. Lloyd George, convinced that agriculture could not hold its own without more knowledge, founded the Development Commission and indicated that one of its activities was to be the prosecution of research in agriculture. This enabled the present system of Research Institutes and Advisory Services to be instituted, the care of which devolved upon an Agricultural Research Council in 1931. For the current year an expenditure of £540,000 on agricultural research in Great Britain has been sanctioned. Though the funds available are still insignificant as compared with the parallel allocations in the United States and Russia, our Research Institutes have established an international reputation for the quality of the work they are doing.

So much for scientific developments: what progress has the practice of agriculture itself shown during the last sixty years? This takes us back to 1879, the black year, when arable farming, already shaking under the rapidly growing imports of wheat and other cereals from America, received a knock-out blow by the almost complete failure of the harvest in a year of unprecendented rainfall.

Almost the only machines then on the farm were the reaper and a few haymaking machines, but a good deal of wheat was still cut by the hook and gangs of seasonal Irish labourers scythed their way through the meadows. The binder was on its way, and within a decade was coming into general use with the invention of the knotting mechanism and the use of twine. The binder reduced the

arable farmers' labour costs, but it was still more effective in enabling the farmers on the western prairies, working single-handed as a rule, to expand their output and put ever cheaper wheat on the European market. By 1894 the price of wheat in England had fallen to 22s. 10d. per quarter, 'Up horn and down corn' had become the policy of our farmers, and grass growing largely replaced the plough except in the Eastern counties. Mechanical science came more fully to the aid of the farmer with the development of the internal combustion engine and the advent of the tractor, which brought increased power and pace to all the operations of cultivation. It is true that the steam plough was an earlier invention of unrivalled power, but it was beyond the resources or needs of the ordinary farmer; it was only economic with large and symmetrical fields, and since it could not replace the horse for the bulk of operations on the farm, it became an emergency tool to be hired for making a summer fallow when the land was too hard for the horse plough to touch, and then it did magnificent work. Though arable farming has continuously declined in England it must not be supposed that it did not progress. Many of the operations formerly thought necessary to the routine of preparing a seed bed were cheapened or omitted without any considerable loss of productivity. The land may not look so clean nor so tidy, but the yields show no falling off. Perhaps they have increased with the shrinkage of cultivation on to the better land, the introduction of improved varieties, and more appreciation of artificial fertilisers, but the statistical methods in use are subject to conservative estimates. It has however become evident that a return to arable farming is more than justified over much of the second-class land of, for example, the Midlands. Tractors supply the power necessary to deal with such land; power harvesters on the lines of American and Australian tools, combined with corn driers, get in the crop rapidly and safeguard it from the vicissitudes of our weather. On the other hand permanent grass in such localities is apt to fall off in quality and accumulate stock diseases; the soil is only productive

with periodical stirring, and pastures only remain healthy when regular intervals of cultivation check the spread of chance infections. In place of the old rotations, alternate husbandry is being widely adopted, leys of three or four years' duration being followed by three or more years of corn. The expensive cultivations necessitated by the root crops are mostly eliminated; the leys with their wild white clover accumulate fertility and humus while yielding more hay and better grazing than the temporary grass. All over the country there are farmers making a success of arable farming, even at the present prices, though their land is not of a class to allow them to grow crops with a large cash return, such as potatoes, sugar beet and vegetables. Of course there must be a sufficient acreage in occupation to provide an economic load for the expensive mechanised equipment, but examples of British farming exist which need fear no comparison with the best work of other countries.

During the period few new crops have been introduced; sugar beet has become important following on Continental practice but is still an exotic, only maintained by heavy subsidies, here as elsewhere, because of the great advances in production from sugar cane. Of the fodder crops marrow-stemmed kale is the only novelty, there has been little improvement in turnips or mangolds to compensate for the increased costs of cultivation and the relative cheapness of other feeding stuffs.

Turning to the more specialised crops, fruit growing has shown great advances in all its branches, for even when I first began to make acquaintance with it the commercial plantation was an unhappy hybrid between the private garden, with its costly if skilful management, and the grow-as-you-please farm orchard. Advance has come with the selection of better varieties (even though the best of all apples, Cox's Orange Pippin, is more than a hundred years old) and with the standardisation of stocks, scientific manuring and spraying, and the improved layout of plantations to secure pollination and economic cultivation. Even forty years ago the planting of Cox's Orange

Pippin was a risky speculation; nowadays its management is so well understood that it has become one of the most trustworthy of all commercial varieties. Preparation for market has improved out of all knowledge; grading and packing, to present the fruit to advantage, and gas storage, to minimise gluts and lengthen the marketing period, have become part of the routine of the new plantations. There are still plenty of neglected orchards to be found up and down England, and plenty of inferior fruit shot on the market, but the work of our best fruit growers is not to be excelled in any country. We still, however, have nothing to compare in magnitude or organisation with some of the great fruit farms of California.

Much the same story is to be told of market gardening; the advances have been great and the improvement has been most manifest of recent years. I doubt if the industry as a whole is yet as efficient as Dutch or Belgian practice or as the work of specialists in the United States. We are still following rather than leading the French with their broccoli, the Belgians with their chicory or grapes, the Dutch with their bulbs, and we still import nine-tenths of the onions we consume, but I doubt if anyone elsewhere can match the work of F. A. Secrett and a few of his rivals. Furthermore the great industry of growing tomatoes, cucumbers and cut flowers under glass is entirely a creation of the last sixty years. The value of its output at wholesale prices is now estimated to amount to nearly 9 million pounds per annum. The fruit growers and market gardeners of the country are active and enterprising men, keen to take advantage of all the new knowledge available, in spite of some rude shocks of recent years from bad seasons and breaking prices.

Sixty years ago British livestock breeders held an undoubted pre-eminence in the world. From the new countries men came to Great Britain for their foundation stocks of Shorthorns and Herefords, Ayrshires and Jerseys; for Lincolns, Romney Marsh and Down Sheep as soon as refrigeration rendered possible the export of mutton and lamb; and for Yorkshire pigs in order to

capture the demands for bacon of our urban population. Our farmers have never lost their interest in breed, and the closing years of the last century saw this or that local race elevated into a breed with its herd or flock book, its schedule of points, its place in the show-yards. Pedigree became a fetish and livestock showing the hobby of every rich man with a place in the country; in many cases a fancy grew up that paid little attention to the economic value of the breed. For the average quality of workaday stock entering our markets, either for stores or for slaughter, by no means showed the same improvement as the pedigree herds. I am told that the stores our graziers have to buy for fattening can no longer compare in quality with the young stock on the Argentine estancias, which are the progeny of a succession of the best bulls that could be bought from Great Britain. Yet the price paid here for a store is far higher than that at which the finished animal enters the frigorifico in Argentina.

The best evidence that we have indulged in a plethora of breeds may be gathered from the operations of the Pig Marketing Board, which after its inauguration in 1931 began to lay down standards of the type of pig the bacon factories required, with a rising scale of prices as that standard was approached. This action has resulted in the predominance of the Yorkshire Large White breed all over the country, just as it had become the dominant factor in the production of bacon pigs in Denmark, Holland and our other competitor countries. Other breeds still maintain a place as foundation stock to be crossed with Large White Boars, but some have shrunk almost to the dimensions of a fancy.

I must not be supposed to suggest that there has been no general improvement in our livestock during the last sixty years. Earlier maturity has been attained, feeding is more scientific and more widely understood, greater prolificacy and better wool are evident in our flocks. Doubtless the greatest improvement to be seen is in connection with milk. The Shorthorns have been specialised for milk production almost into a breed distinct from

the beef shorthorns; the Ayrshires have made notable advances, the Dutch black and white race, as British Friesians, have become prominent again by reason of their deep milking qualities. The figures supplied by the Milk Recording Societies, though they only cover a fraction of the herds, show how steadily the yield per lactation has increased, owing to selection in breeding, more scientific feeding and greater attention to management. In certain districts the methods of A. J. Hosier have caused almost a revolution in the economic production of milk, attended by the restoration to cultivation of land that was falling down to the most miserable sheep-walk. It is as yet too early to prophesy how far Hosier's method can be extended, how far it may not lead to that national desideratum—more and cheaper milk.

The handling of milk has received constant attention and has been entirely reformed, for milk, essential and universal food as it is, may become one of the most dangerous. Cleanliness in everything the milk comes in contact with is the prime necessity, and apart from public health regulations greater care in handling milk has been forced upon farmers by the way the distributing agencies have abandoned the dual delivery of morning and evening milk. The milking machine, besides its importance in saving labour, has helped to keep milk free from accidental contamination in the cowshed; in the best practice the milk is never in contact with the air during its transit from the udder to a protected receptacle. I need only mention the steady increase in the production of milk from tubercle-free herds, thus ensuring the protection of young children from the risk of an infection that may prove disabling at some later date. The way is clear to something like the complete eradication of bovine tuberculosis, a reform as necessary to the farmers as to the public health, so much does this disease curtail the productive life of the milch cows of our country. The manufacture of milk into butter and cheese has been standardised, whereby many losses and much inferior produce have been eliminated. It is true that butter has become a product of small

interest to the British producer, so severe is the competition in an article which can now travel unimpaired from the Antipodes; standardisation also is not without danger to those fine products of the old agriculture—the noble cheeses like Stilton, Cheshire and Wensleydale. But as a small boy I used to see whole milk being churned without any regard to temperatures or acidity, or any of the exact knowledge that now prevails as to the manufacture of butter and cheese.

I must now in a very brief fashion try to set out the changes that British farming as a whole has experienced during the last sixty years. It has been a time of sudden and violent changes, creating exceptional difficulties for an industry like agriculture in which there is a long lag between preparation and realisation. The period began in the middle of the growing depression which reached its nadir in 1894-5, and then slowly passed into something like quiet prosperity in the first decade of the present century. The War brought great difficulties but soaring prices, followed by a crash in 1921 when the fictitious prosperity had to be liquidated. From 1923 to 1929 conditions were relatively stable, but at the end of 1929 set in another crash of prices from which we have not recovered, indeed the slump has been renewed within the last year. Farmers then have had to face three major depressions within 60 years. The diagram Fig. 1. shows some of the changes in the use of the land during the period, a loss of over 2 million acres of cultivated land due in part to increasing urbanisation and in part to the abandonment of marginal land. More significant is the continuous decline in arable cultivation—six million acres or 33 per cent, spread pretty evenly throughout the period. Now this represents a definite falling off in production, for from every point of view—whether life-sustaining power of the food grown or the cash value of the produce—the output from grass is below that from an equal area of arable land. Naturally the area under corn crops has declined with the arable land, but it is significant that the acreage under turnips and swedes has decreased in even greater

proportion, because of the labour costs on these crops. To some extent of course the new sugar beet has taken the place of other roots, especially in East Anglia, but as indicated earlier, this growth of sugar beet cannot be regarded as a normal commercial enterprise. On the whole these statistics present an ugly picture of cultivation in a decline, and most qualified observers going about the countryside would agree that the statistical evidence is confirmed by the neglected appearance of much of the land. On the other hand I cannot show you how the market gardening and fruit growing has expanded, for the earlier statistics are imperfect and do not compare with recent figures.

The next diagram Fig. 2 gives the numbers of livestock, and here we see considerable increases in milch cows and pigs; sheep however have declined. Coupled with earlier maturity this means an increased output of meat and livestock products, to which again we may add a remarkable advance in the production of eggs and poultry since the War. It is often stated that this expansion of livestock production makes up for the loss of arable cultivation, and that the Census of Production indicates no decline in the gross output of our agriculture. This is approximately true when the figures are corrected for changes in value, but it fails to take account of the fact that the bulk of the increase in live stock products has been made out of imported feeding stuffs and not out of the growth of our own land. Milch cows to a large extent, cattle in the final stages of fattening, pigs and laying hens almost wholly, are fed upon wheat offals (80 per cent imported), imported barley and maize, and the residues of the immense importation of oil seeds. We must also allow for the considerable increase in the numbers of store stock imported for fattening or milk production. In fact the increase in livestock output in the main represents manufacturing rather than farming, requiring a minimum of land and comparable with the manufacture of margarine from imported copra and whale oil with a certain amount of milk for flavouring purposes. Taking this into account

we must admit a very considerable decline in British agriculture, of which the loss of arable acreage is indeed the index.

My next diagram Fig. 3 shows the changes in the population employed upon the land, beginning with the census of 1871. The shorter line on the graph shows the number of labourers from the returns collected by the Departments of Agriculture on a somewhat different basis from that of the census returns. Both sets of figures tell the same tale, the drift of men out of farming, something like 8,000 a year over the whole period, more of recent years. To some extent the loss of men represents the introduction of the machine—fewer men but increased effectiveness for those that remain, but the greater rate at which men have been leaving in the last few years indicates that the agricultural industry has not been able to offer prospects that will retain men against the competition of other industries for labour. It is evident that farming as it is generally being practised—the farming to which most men were brought up—cannot be continued; it must run down because of the lack of men. Indeed one is told that in many districts there are none but old and partially disabled men left on the farms; the migration has been heaviest among the men under 21, so that the average age of the workers remaining has steadily risen. This is perhaps the strongest evidence we could have that agriculture as an industry is on the down-grade.

What has brought about this state of affairs? Here is a diagram Fig. 4 showing the price of wheat per quarter year by year throughout the period. Though wheat is only one product of arable farming its price forms a very fair index of the returns to be expected from the cultivated land. Alongside is the graph of wage rates during the same period, an arbitrary figure selected from one county only, but sufficient for purposes of comparison. Many representatives of the farming interest would claim that this diagram sums up the whole story of agricultural depression, and that unless prices can be restored to a parity with wages farming cannot be carried on. Before

the War a sack of wheat (half a quarter) paid a week's wages; there have been times recently when the sack of wheat would only pay one-third or one-quarter of the weekly wage of a labourer, a wage which competition has already forced above the statutory minimum. But have not other industries been subject to much the same experience of rising wages and lower prices for their output? The graph, Fig. 5, I now put before you shows the price index of agricultural produce compared with the price index of commodities at large—metals, textiles, housing materials etc. It does not cover the whole period, the agricultural index being available only from 1911, but it is evident how parallel a course the two graphs pursue. The decline in prices and the successive depressions are not peculiar to agriculture; they have been brought about by factors outside agriculture itself, factors which affect all articles in the world's markets. Nor are agricultural depressions peculiar to Great Britain; they prevail in every country, old or new, with greater or less intensity.

It is indeed a depressing conclusion to my story, that so much advance in the science of production, so much enhanced power to give to every man the prime basis of life, should have been accompanied by so serious a decline in British agriculture. What is the reason; why should the increased capacity to give people the more abundant and better food that they are in urgent need of, that indeed is necessary for a virile population, have been so lamentably frustrated? Let us not blame farmers that they have not assimilated the knowledge of the extended powers that science provides. Farmers are much the same as people in other businesses, some good, some indifferent, a few bad. But all the science that exists can do little to help the average peasant or even the average small farmer. He lacks capital and credit, his holding cannot adopt the methods that would make the land profitable. Consider the farm of one to two hundred acres on second class land, mostly in grass; it would produce a modest return per acre under the plough, but the powerful equipment required to handle the land economically would

overweight the small acreage. The fields want rectifying and draining, how is he as a tenant to bear the cost, even if the drainage is not rendered inoperative by the state of farms above or below him? With fertilisers he may improve his grass and carry more livestock, but how is he to obtain first-grade animals? Again trading on his small scale, how can he buy or sell economically? By co-operation, perhaps, but for all its virtues co-operation cannot meet all his difficulties even if he is willing to accept the discipline. After all, co-operation is only a means of organisation, partial at that, for it does not touch the land itself. It is true that one hears of peasants who die wealthy and of men who make a few acres a stepping stone to a large and prosperous business, just as there are millionaires who began life by selling matches in the street, but you cannot organise an industry on the assumption that such men will be generally available. Nor must we blame science, though in the train of science have come the difficulties of agriculture the world over. Science is impartial, it confers power but it cannot control the way in which the power shall be employed.

In the main the difficult position of agriculture arises from circumstances outside its own control. Agricultural prices have only fallen step by step with the prices of other commodities; a fundamental difficulty of the industry lies in the deficient purchasing power of the community, so that looking at agriculture by itself, it would seem to be suffering from overproduction.

Externally this would appear to be caused by the increased output of the new countries brought into the market by science, cheap transport and commercial organisation. Internally, also there are sufficient men equipped with the new methods to make competition severe for the majority of farmers. Politicians have attempted to check overproduction by creating an artificial scarcity by means of protection. But nothing really checks the enlarged powers of production. When Australian farmers find it no longer pays to send wheat to England they turn wheat into eggs and a new market of

the home farmer is attacked. Only a completely closed national economy can make protection effective, and then internal overproduction may have the same depressing effect upon the price. Protection and artificial scarcities as a remedy for low prices always remind me of an analogy employed by Herbert Spencer. If you have, he writes, a sheet of brass with a bulge in it, the obvious thing to do is to put it on a flat surface and hammer the bulge down. Actually however the bulge grows under such treatment.

It would be beyond the scope of this discourse were I to begin to discuss the possible remedies for a distressed agriculture. But I cannot forbear from putting before you the view that neither the farmers nor science is to blame, but that the structure of our farming has become antiquated until it can no longer take advantage of the new powers at our disposal. The last hundred and fifty years have seen the complete transformation of other industries. The hand loom has given place to the power loom, such looms have been organised into larger and larger units, always with a gain of efficiency and cheapening of the product. While there are obvious limits to the industrialisation of agriculture, impossible indeed on certain kinds of land, only some such process can give scope to the potentialities created by modern science, machinery and organisation. At the same time we must be prepared for the reconstruction of our system of distribution of the farmers' products in order to adapt it to the present immense aggregations of population into towns. Our methods of trading grew up at a time when producers brought their wares into a neighbouring market and sold them directly to consumers. Nowadays they have to cater for a world market, or at least a national market, in which as an individual the farmer has no control over the prices. Let us not suppose that the structure of our farming, or our present land system, is immutable; history shows us how it has moved from a sort of communal farming into the several ownership that we may call peasant or yeoman farming, which in its turn passed into the larger tenant farming units that are proving inadequate to-day. Each of these systems

answered in its day, each decayed under economic pressure and was transformed in response to new requirements from the community at large. The change was never sudden and in its progress inevitably brought individual hardship and many apprehensions that the prosperity of farming was at an end. Nor did it ever embrace the whole rural community, as still may be seen in the dominance of peasant holding in many European countries.

Change must come; it will be decay if we attempt to stabilise the system. There is no lack of examples in Britain to show that the right men under proper conditions can make farming pay even at the present range of prices. We need not fear that the farmers will be displaced, they alone can handle the land; what is needed is to give them an environment more fitted to the times, even though it may involve considerable reconstruction of our land system.

Again I say that we must be prepared for big changes in the social structure if our agriculture is to be restored to the place it could occupy in the national economy, if indeed many elements of our population are to be properly fed.

It has become a threatening world; we can only secure ourselves if we consent to work to a plan, never by drifting.

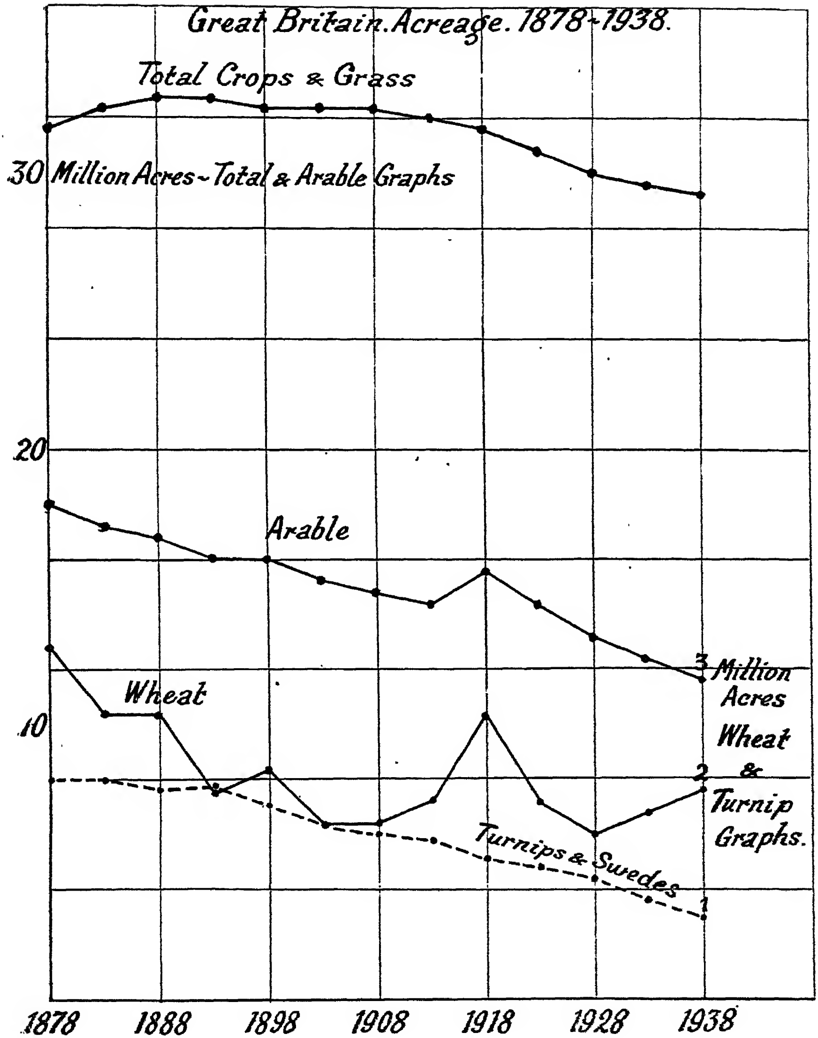


Fig. 1.—Changes in acreage, 1878-1938.

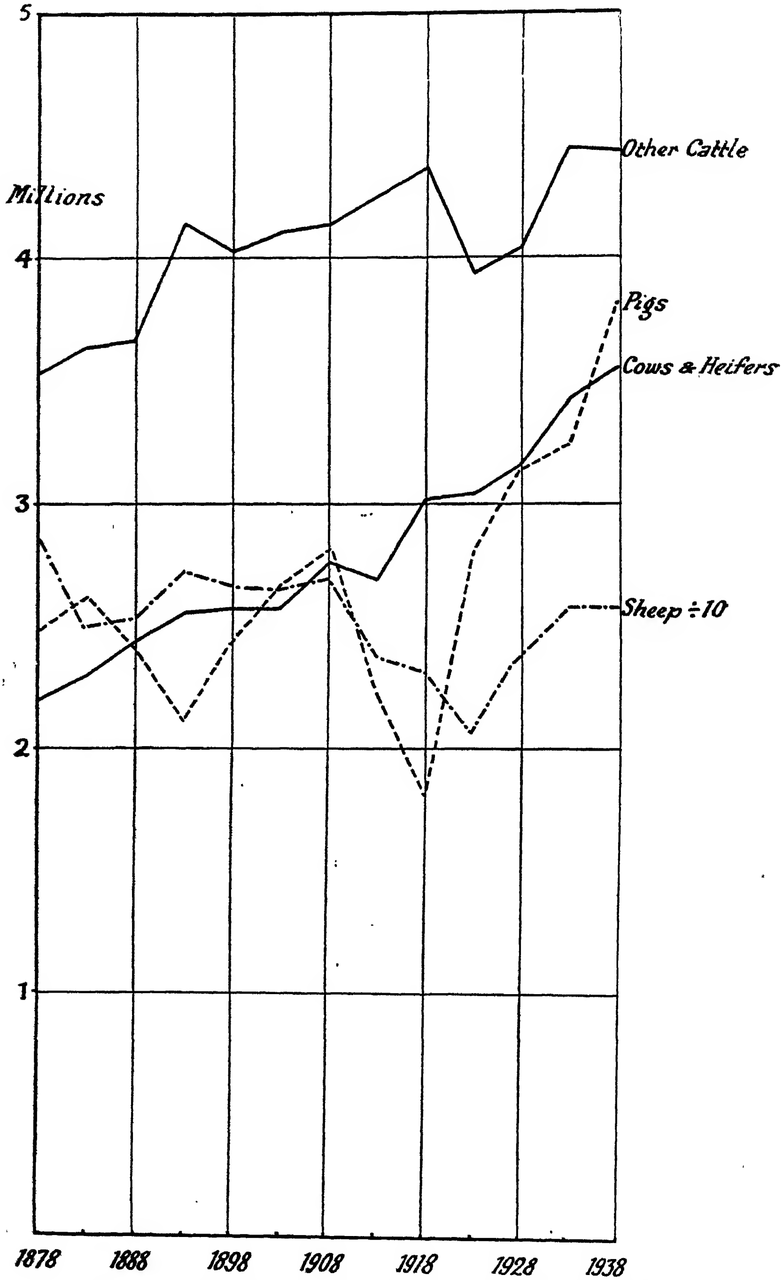
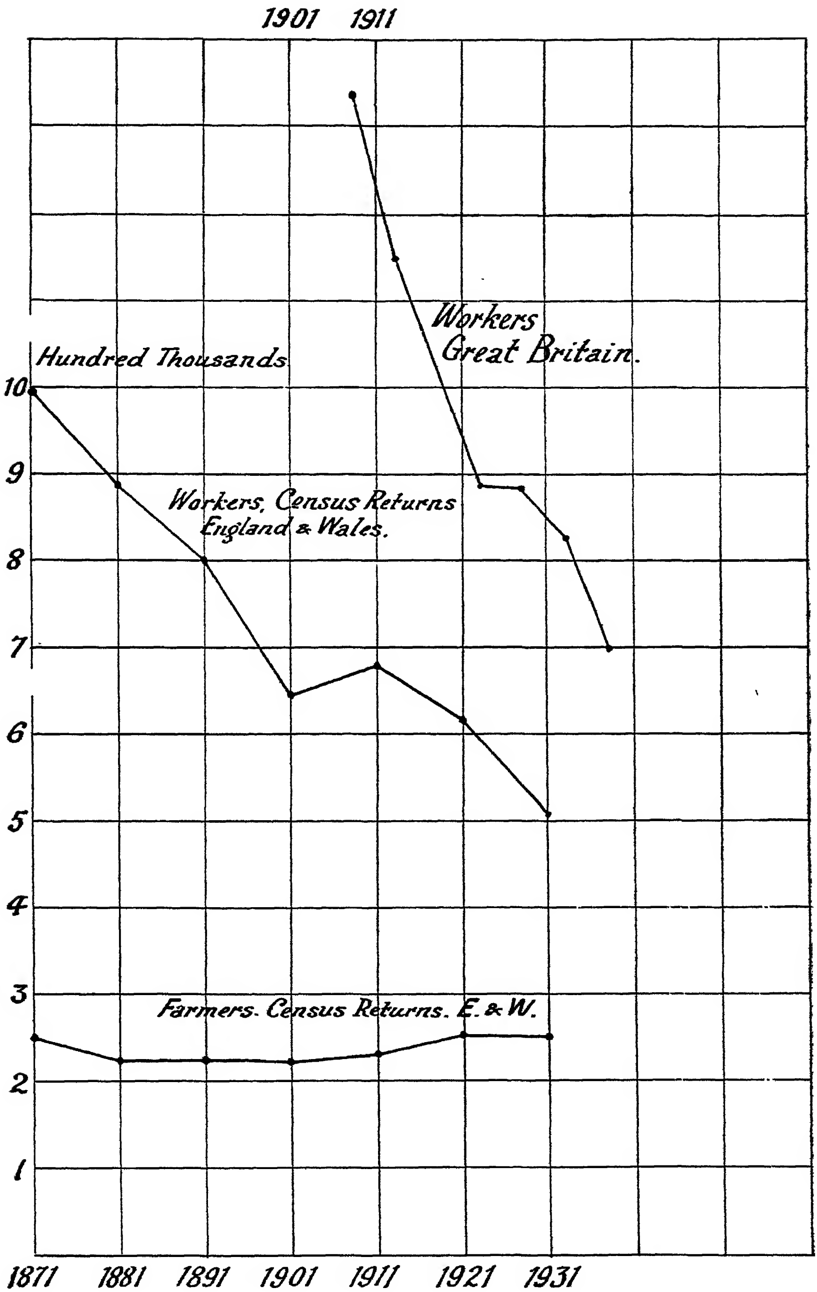


Fig. 2.—Changes in the number of Live-stock, 1878-1938.


1901 1911
Hundred Thousands
Workers Great Britain.
Workers, Census Returns England & Wales.
Farmers. Census Returns. E. & W.
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1871 1881 1891 1901 1911 1921 1931

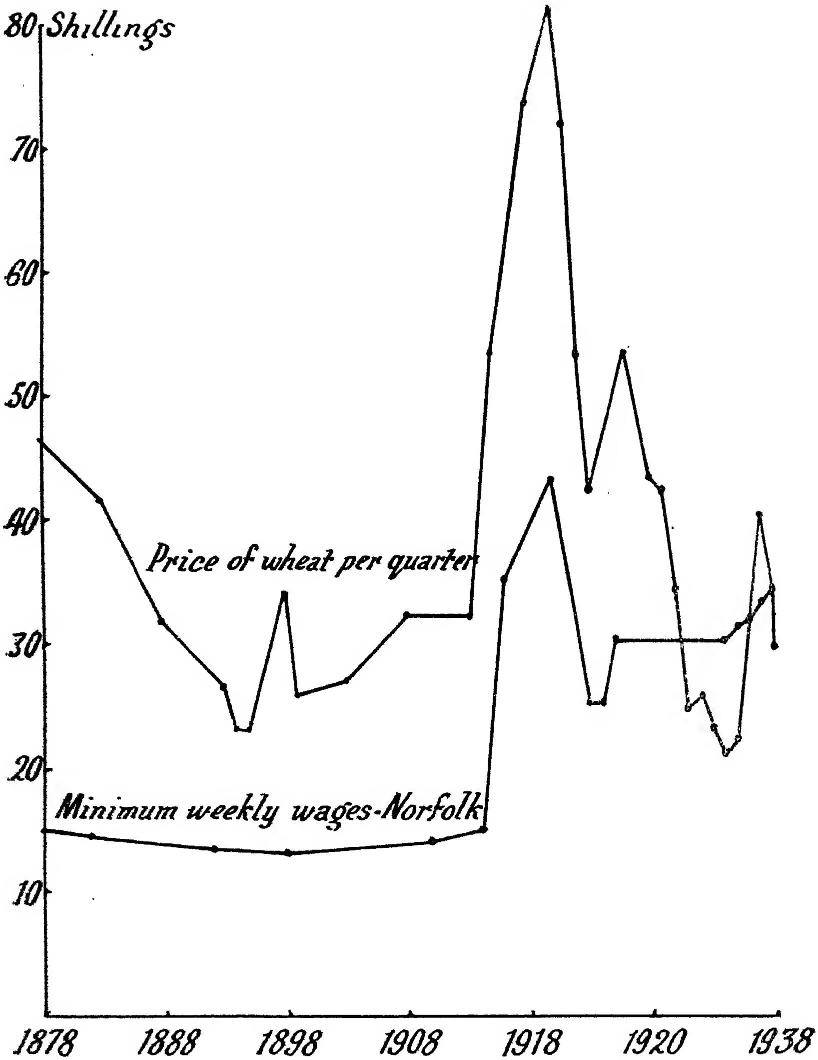

Fig. 4.—Comparison of Wheat prices and weekly rate of wages, 1878-1938.

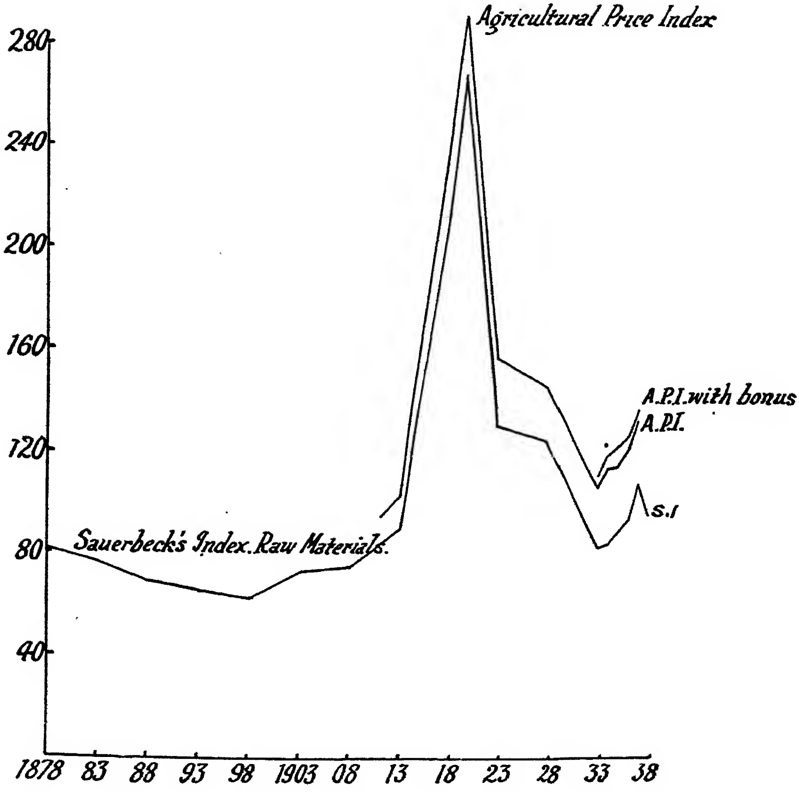

Fig. 5.—Comparison of agricultural and general price indices.

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CONTENTS

SUNSPOTS AND INSECT OUTBREAKS: AN EPIDEMIOLOGICAL STUDY.

By
D. Stewart MacLagan, D.Sc., (Edin.), Ph.D., F.R.E.S.
(Lecturer in Zoology, University of Durham.)

I. INTRODUCTION.

The quantitative study of animal populations—their densities, migrations, and fluctuations—is generally recognised as one of the most important branches of modern animal-ecology. Studies of this kind have shown that one of the outstanding characteristics of animal-populations is their instability. For this reason, it seems customary nowadays to criticise Darwin for using the phrase 'balance of Nature,' since biological associations are in a continual state of flux, and there is no balance in Nature. The writer cannot accept this interpretation of the phrase, for it seems that what Darwin really implied was not a static balance, but a dynamic equilibrium, such that animals vary in abundance in response to a continually changing environment, while various factors operate in such a way as to prevent undue oscillations of the pendulum. The object of this paper is to attempt to demonstrate that the fluctuations of insect-populations do not take place entirely at random; or in other words, there would appear to be some degree of regularity in their recurrence, when viewed over a sufficient number of years.

The probable existence of some regularity in the fluctuations of animal numbers has been a subject of study by several workers. As long ago as 1883, Swinton[1] considered the problem in relation to outbreaks of Locusts, and concluded that outbreaks of the Rocky Mountain Locust *(Melanoplus spretus, W.)* coincide with sunspot-minima. Simroth[2] suggested that the fluctuations in numbers of animals are associated with the variation in numbers of sunspots, and that different species exhibit a differential response to the variation. Several authors published evidence in support of Simroth's contentions, but contradictory evidence was adduced by others. Recently, Criddle[3] has studied the outbreaks of grasshoppers in Manitoba, and finds that there is a good

pointed out the cyclical nature of the fluctuations in numbers of the fur-bearing animals of Canada; and Elton[5] has shown that these cycles are synchronous with those of some species in Scandinavia, a fact which naturally suggests that a general climatic pulsation is the primary cause. This survey of the pioneer work on the subject shows that the idea of a more or less rhythmical fluctuation in the numbers of animals living in a natural environment has been investigated on several occasions, but the evidence has not always been convincing. This is not surprising in view of the difficulty of obtaining accurate, and sufficiently detailed, records. However, evidence in support of this contention is gradually accumulating, especially in regard to wild mammals. The following surveys of severe insect-outbreaks in Britain include some of the few available records extending over a considerable number of years; and are, therefore, all the more valuable (indeed essential) for the establishment of a periodicity..

II. HISTORIES OF SOME NOTABLE EPIDEMICS.

1. *Ague.* This disease is generally accepted as having been malarial in character and transmitted by mosquitoes. One of the earliest chronological records of an ague-epidemic is the one which raged over England during the two seasons of 1557 and 1558. There are several references to these epidemics in the works of early chroniclers. The fever of 1558 was particularly acute, and Stow refers to it as a 'quartan ague.' The so-called 'gentle correction' of July and August, 1580, was also an aguish complaint, and not only caused considerable mortality in England, but also among the troops in Ireland[6]. The autumn of 1612 was certainly an ague-season, for when the eldest son of James I died, a letter writer of that time says, "It is verily thought that the disease was no other than the ordinary ague that hath reigned and raged almost all over England since the latter end of summer."[7] In 1625 there appears to have been a fairly wide-spread harvest-ague,

and in 1638-39 there was " a malignant fever raging so fiercely about harvest that there appeared scarce hands enough to take in the corn."[8] Again, in 1651 there is evidence of an ague which broke out in the seaside villages of Cheshire, Lancashire, and N. Wales. Sydenham's first aguish ' constitution ' commenced in 1661 and declined gradually till 1663, after which there was no recurrence until 1678.[9] This was one of the most noteworthy of the malarial epidemics. Among the many sufferers was King Charles II, who had a severe attack of ague in September, 1679. Following this outbreak there is a long interval of freedom from aguish complaints until the years 1727-29. During these three unhealthy years the burials at Norwich were nearly double the registered baptisms; and Patrick Walker[10] refers to " the burning agues, fevers never before heard of in Scotland " as " evidence of God's displeasure appearing more and more against us since the incorporating union." The latter quotation is in reference to the Union of the Parliaments of England and Scotland in 1707.

During 1754, spring-agues were recorded as fairly frequent in Carlow and Kilkenny,[11] but there appears to be no evidence of any malarial fever in epidemic form until the years 1780-84. Referring to the spring of 1781, Barker[12] says " that very peculiar, dangerous, and obstinate disease, the burning, or as the people in Kent properly enough called it, the Plague-ague, made its appearance, became very epidemical in the eastern part of the kingdom, and raged in Leicestershire, the lower part of Northamptonshire, Bedfordshire, and in the fens." Concerning the autumn of 1782 a Liverpool writer says, " the quartan ague was very prevalent on the opposite shore of the river in Cheshire; it was universal in the neighbourhood of Hoylake, where many died of it."[13] In 1784 there was an epidemic along both sides of the Severn valley.[14]

At this time agues became epidemic in Scotland, as revealed in the records of cases treated at the Kelso dispensary. The table compiled by MacKenzie is quoted by

Year	Interval	Sunspot Max.	Dev. from Max.
1580	—	—	—
1612	32	1615	— 3
1625	13	1626	— 1
1638-9	13	1639	— 1
1651	13	1649	+ 2
1661-3	10	1660	+ 1
1678-9	17	1675	+ 3
1727-9	49	1727	0
1780-4	53	1778	+ 2
1826-8	46	1829	— 3

Table I. Epidemics of Ague in Britain.

Ritchie[15]. It is known, of course, from the 'Statistical Account of Scotland (1791-99)' that certain parishes (e.g. Dron, Arngask and Cramond) were notorious for the prevalence of endemic ague. After the great epidemic of 1780-84 there followed a progressive decline in aguish complaints, indeed almost to extinction, but with recrudescences in 1826-28[16] and 1846-47[17]. The latter could hardly be called an epidemic, but has been mentioned on account of the interest attached to it as being the last outbreak of any importance in Britain.

2. *Antler Moth.* The first reference to an epidemic of this insect in Britain is in an old agricultural journal—The Farmer's Magazine[18](1802). Therein is an article entitled, 'Account of the Worms which Infested the High Sheep Farms in Tweeddale in the months of June and July last'; and from the description of the larva there is no doubt it was that of the Antler Moth. The writer says, "a similar devastation visited the sheep pastures in this

country in 1759." The caterpillars were again destructive in 1824 on the high lands of Dumfriesshire. Duncan[19] gives an excellent description of the Antler Moth epidemic which occurred over a large portion of Skiddaw in 1824. The account of the ravages concludes by saying that "the quality of the newly grown herbage (6 yrs. after) was materially improved, thus affording another instance of the indirect advantages derived from insects." The hill pastures of the Scottish borders suffered severely from this pest in 1836 and the few preceding years.[20]

Then follows a lapse of over 40 years until 1881, when Miss Ormerod received caterpillars from Clitheroe, (Lancashire) where their ravages were serious but localised.[21] In 1884, the upland pastures of southern Scotland were very severely damaged by a similar plague, which extended over seven counties, and was particularly severe in Ettrick and Yarrow[22] (Selkirkshire). The caterpillars continued their ravages over many of the same areas in the following year. In 1894, hill pastures were injured over a wide area, extending from Roxburghshire to Ayrshire;[23] and in 1917, an outbreak of equal severity damaged the mountain pastures of northern England from Derby to Westmorland.[24]

Year.	Interval.	Sunspot Max.	Dev. from Max.
1759	—	1761	—2
1802	43	1802	0
1824	22	1829	—5
1835-6	12	1837	—1
1884-5	48	1883	+1
1894	10	1893	+1
1917	23	1917	0
1937	20	1938	—1

Table II. Epidemics of Antler Moth in Britain.

The most recent outbreak occurred in 1937. Cameron[25] says, "the outstanding entomological events in Scotland in 1937 included an intense outbreak of the Antler Moth in the central and southern uplands." In the Ochil Hills, about 30 square miles were involved, 9 square miles of the Campsie Fells were infested, and the caterpillars were reported as being present "in their countless millions" in southern Ayrshire and Kirkcudbrightshire. The affected pastures lay at an elevation of 700 to 2000 feet.

All these epidemics of the Antler Moth were so severe and widespread in their occurrence that they could not escape the attention of the most casual observer. Indeed, there are repeated references to the myriads of caterpillars leaving the hill-sides bare behind them, to the choking of mountain streams, and to masses of them being held up by the low stone dykes so characteristic of the Border sheep-country.

3. *Diamond-Back Moth.* As with the Antler Moth, so with the Diamond-back; while individuals may be taken any year in most localities, there are periodic increases in the population sufficient to constitute a 'plague.' It appears that the first recorded plague-year of the insect is that referred to by Curtis,[26] writing in 1842, when he remarks, "I have little doubt that this was the caterpillar (Cerostoma xylostella) which Mr. Dalgavings of Forfarshire mentioned as having seriously injured his crop of turnips in 1826." He then alludes at length to a severe attack on turnips in Hampshire in the late summer of 1837. The next recorded epidemic is that of 1851, when Stainton,[27] writing of the species, says "It was excessively abundant throughout the country; the turnip growers thought some new blight had fallen upon their crops, but fortunately subsequent years have not shown a continuance of the inordinate numbers." There was a localised outbreak in Berwickshire in 1863 and Ormerod[28] remarks, in her report for 1883, that the moths were excessively numerous in Yorkshire and the eastern counties of England and Scotland.

Year	Interval	Sunspot Max.	Dev. from Max.
1826	—	1830	— 4
1837	11	1837	0
1851	14	1848	+ 3
1883	32	1883	0
1891	8	1893	— 2
1901	10	1905	— 4
1914	13	1917	— 3
1926	12	1928	— 2

Table III. Epidemics of Diamond-Back Moth in Britain.

In 1891 there occurred one of the most alarming epidemics of Diamond-back moth that has ever been recorded in Britain, and the literature (agricultural and entomological) is full of references to the great damage done to the turnip-crop of that year—for long remembered by agriculturists as "the year of the caterpillar plague."[29] MacDougall,[30] in his report to the Highland and Agricultural Society for 1901, says he had "many complaints about P. cruciferarum;" and in 1914, he records an outbreak of the moth as "extensive and serious." Similarly, it is noted by Gray[31] that "the caterpillars of this small moth caused much loss of crop throughout the country . . . in only one or two years has the moth been able to multiply to such a degree as to lead farmers to expect a repetition of the losses experienced in 1914." The last outbreak took place in 1926, being most severe in the south-eastern counties of England, according to Fryer.[32]

4. *Leather-jacket.* Another illustration of these periodic epidemics of insects is provided by a species which is well known to agriculturists as "the grub." Despite

the looseness of the term, the farmer has a particular species in mind, when speaking of "grub," namely, the Crane-fly larva, or leather-jacket. The species of economic importance are *Tipula paludosa* and *T. oleracea,* and when an epidemic occurs in Britain usually both species are involved, with a preponderance of *T. paludosa.*

One of the earliest references is contained in a note entitled, 'Observations on the Natural History and Recent Ravages of the Grubworm,' in The Farmer's Magazine (August, 1817). The correspondent says, "the complaints of its depredations on the present growing corn crop, where it has succeeded an herbage one, are very general and loud . . . the last crop that was materially injured by the grub was that of 1800."[33] Curtis,[34] writing of Crane-flies, says "Their numbers depend very much upon the seasons, and for this reason sometimes these troublesome larvae are not seen. I believe they abounded in 1816, '17, '18, and then were lost sight of till 1829." In June, 1845, they committed great havoc amongst Swedish turnips in the Isle of Anglesey. Again, in the Gardener's Chronicle (May, 1858) a correspondent writes as follows. "What can be done for the parks of London? They are suffering from the inroads of a formidable enemy. All about Stafford House, in the Green Park, and in the Regent's Park, the turf is vanishing . . . the surface in the early morning is alive with leather-coated grubs."

In her annual reports, Ormerod[35] treats the outbreaks of 1880 and 1884 in great detail, and comments on the former as being "the great insect attack of the year." She also refers at length to the devastation wrought in 1892. Incidentally, during the epidemic of 1884 serious injury was done to the turf of Lord's cricket ground. Regarding the plague of 1904, MacDougall[36] says, "complaints were frequent as to the destructive work of the Leather-jacket." The crop-report of the Department of Agriculture for Scotland[37] characterises the outbreak of 1917 as "a serious and widespread attack of grub."

Year	Interval	Sunspot Max.	Dev. from Max.
1800	—	1802	—2
1817	17	1816	+1
1829	12	1830	—1
1845	16	1848	—3
1858	13	1860	—2
1880-4	22	1883	—3
1892	12	1893	—1
1904	12	1905	—1
1917	13	1917	0
1925	8	1928	—3

Table IV. Epidemics of Leather-Jackets in Britain.

The last plague occurred in 1925; and Fryer[38] summarises the situation in England in these words—"Leather-jackets were the most serious pest of cereals." The district reports of the Department of Agriculture for Scotland[39] constitute a tale of woe regarding the oat-crop, with comments such as, " grub very prevalent," " lea-oats much affected with grub," " badly smitten with grub," and so on.

5. *Turnip Flea-beetle.* Turnip flea-beetles (or ' fly ') are another excellent subject for studying the periodic outbreaks of insects, as the damage they do renders them familiar to agriculturists and makes them subjects of comment in agriculture and entomological literature. On this account, numerous records are available for over a century. One of the earliest recorded outbreaks is that of 1816 (in The Farmer's Magazine,[40] for August of that year), the following comments being typical. " Turnips that were early sown have suffered much;" " our turnips

have again been seriously injured," "many crops injured by the fly." Curtis[41] comments on a serious attack of turnip flea-beetles during the summer of 1826. In 1838, "the flea-fly was very busy;" and "their old enemy, the fly, made great ravages among the turnip."[42] Another attack occurred in 1848, but no serious injury was done until 1859, when the summer was unusually dry, and "the turnip-fly increased to an extraordinary degree, entire fields being swept away by it in the course of a few days."[43]

Year	Interval	Sunspot Max.	Dev. from Max.
1816	—	1816	0
1826	10	1830	—4
1838	12	1837	+1
1859	21	1860	—1
1881	22	1883	—2
1899	18	1905	—6
1914	15	1917	—3
1930	16	1928	+2

Table V. Epidemics of Flea-beetles in Britain.

There was comparative freedom from the pest during the '60's and '70's, but a devastating attack took place in 1881. Miss Ormerod[44] gives a splendid account of this outbreak, and summarises it in these words—"turnip-fly was little short of a scourge over a large part of England and Scotland." An attack was reported from the east of Scotland in 1892, and there were complaints of serious injury to turnips from almost every county in Scotland in 1899. The severity of these attacks may be gauged from the district reports in the Transactions of the Highland

and Agricultural Society of Scotland.[45] MacDougall[46] refers to the damage done by flea-beetles to turnips, in 1914, in his annual report on injurious insects.

The numbers of the pest were distinctly above the average in 1926, but there was no recurrence of abnormal damage until 1930, which was "an exceptionally bad year . . . and only the south-east counties escaped bad infestations."[47] In these epidemics of 'fly' in turnips, usually two species are concerned, and occasionally a third one, but on the whole the chief culprit is *Phyllotreta undulata.* Although the latter species and *P. nemorum* differ slightly in their life histories, the general ecological requirements of the two species are somewhat similar.

6. *Cutworms.* As a final illustration of the periodic fluctuations of insect-populations, certain species of the family Noctuidae may be considered, since reliable records of the major outbreaks during the last 100 years are available. The larvae constitute some of the most serious pests of crops in America and Russia, but it is the species known as 'cutworms' or 'surface-caterpillars' which are of special importance in Britain. In a serious outbreak, three or more species may be concerned, but only two are of prime significance, namely the Turnip Moth, *Euxoa (Agrotis) segetum,* and the Heart and Dart Moth, *Feltia exclamationis.* Of the two species, *Euxoa segetum* is almost invariably the most numerous, sometimes constituting ninety per cent of the cutworms present during an epidemic.

Some of the earliest records concern several notable epidemics which occurred in the first half of last century. Curtis[48] (writing in 1843) says, "the surface-grubs have been noticed more than a century ago, and in 1818, 1826, 1827, and 1836, but few vegetables escaped their ravages; and they occasioned so serious a loss to the farmer that the Entomological Society of London considered the subject fit for a prize-essay." Another excellent observer of Nature, Duncan,[49] says that "in the

autumn of 1826 the larvae abounded, and in June following the imago swarmed, the hedges for nearly three weeks being literally alive with their multitudes;" while Towers[50] refers to "enormous damage in Berks, Bucks, and the south-eastern counties by *A. segetum* in 1836." Then follows a lapse of thirty years until a really serious outbreak recurred, namely, in 1866, when "the turnip and other root crops suffered to a most destructive degree by grubs"[51] which Dr. Carte found to be *Agrotis segetum*. In 1881, Ormerod [52] reported serious injury by surface caterpillars (mostly *A. segetum*) in such widely separated counties as Dumfriesshire, Hertfordshire, Kent, Hampshire, Norfolk, and Devon; and again, in her report for 1885, there is evidence of the damage wrought by the larvae, there being complaints such as—"we had an enormous quantity of *A. segetum* larvae in our plots" (Cirencester); "surface grubs were plentiful and no crop was free from their inroads" (Barking); "committing great ravages, both on swedes and turnips" (Devizes).[53]

Year	Interval	Sunspot Max.	Dev. from Max.
1818	—	1816	+2
1826-7	9	1830	—3
1836	9	1837	—1
1866	30	1870	—4
1881	14	1883	—2
1896	15	1893	+3
1902	6	1905	—3
1921	19	1917	+4

Table VI. Epidemics of Cutworms in Britain.

The next outbreak of note occurred in 1896, Ormerod[54] summarising the outbreak thus—"surface caterpillar was

the chief agricultural infestation of the year; it was widespread, did much mischief, and lasted for a long time . . . the caterpillars proved to be, for the most part, *A. segetum*." The year 1902 was also noteworthy for cutworms, Theobold[55] having reported " a serious outbreak of these pests." The amount of damage done by cutworms was distinctly above the average in 1917 and 1918, but not until 1921 was there a recurrence of their numbers in epidemic proportions. Fryer[56] comments on the outbreak as follows—" It would seem necessary to go back to the year 1818 to find an epidemic of equal or greater importance . . . the whole of England was affected, more or less, but it would appear that the greatest damage was caused in the southern, south-eastern, and midland counties . . . the species concerned seems to have been, in the main, the Turnip Moth *(A. segetum)*."

These epidemiological surveys include *all* the major outbreaks of the species concerned—none having been omitted, as far as the writer is aware, after an exhaustive search through a variety of literature. Hence, we are now in a position to view the epidemics in retrospect, and to survey the evidence in support of a periodicity in their appearance.

III. SURVEY OF THE EVIDENCE FOR PERIODICITY.

The data concerning the occurrence of these epidemics have been summarised in Tables I-VI. It is apparent that severe outbreaks (not merely endemics in restricted foci) occur at intervals of *about* eleven years, or a multiple of that figure. The average length of the period is obtained by totalling the number of years between successive outbreaks and dividing by the number of intervals, the latter being assessed as ' one ' when the span of years approximates eleven, ' two ' when it approximates twenty-two, and so on. By inspection of Table VII, it will be observed that the period between severe outbreaks of all these species

fluctuates about a mean of eleven years; but occasionally the rhythm is broken, and the regular pulsation 'misses a beat.' This lapsing of the rhythm in certain instances, notably the ague-epidemics, may be real, or the result of gaps in the historical records at this early period.

Epidemic	*Ague*	*C. graminis*	*P. maculipennis*	*T. paludosa*	*P. undulata*	*E. segetum*
Aver. Int. (Yrs.)	11.2	11.1	11.1	11.3	11.4	10.2
	Cycle of years = 11 x n (n is a whole number)					

Table VII. Cyclical Occurrence of Insect Epidemics in Britain.

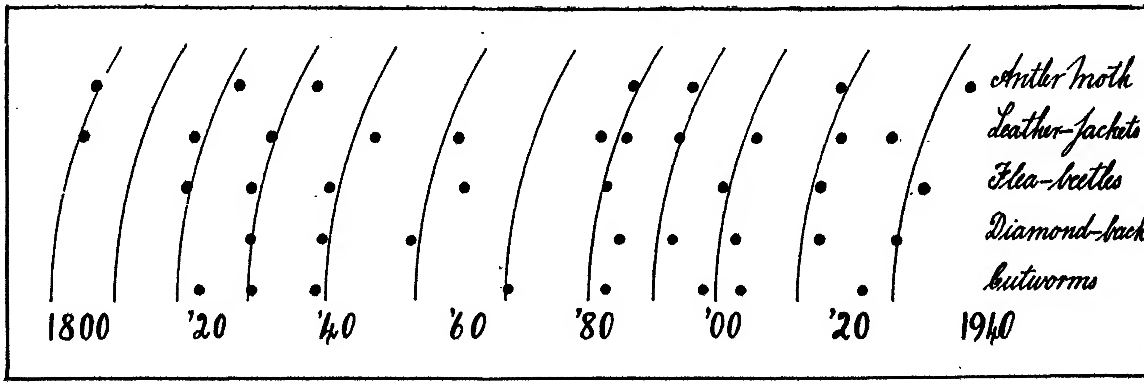

Fig. 1.—Diagrammatic Representation of the Cyclical Trend in the Occurrence of Insect Outbreaks in Britain.

Moreover, when the data are plotted in the manner indicated in Fig. 1, there is revealed a distinct *trend* in the *order of occurrence* of these major outbreaks, indicative of some universal underlying cause, cyclical in character. From the available evidence, then, the population-fluctuations seem to have an intriguing suggestion of design, if one could only discover the key to their explanation. Sometimes a problem of scientific interest lies on the borderline of different fields of investigation, and this one is an excellent example. In casting about for some solar or meteorological parallel to the period suggested by the above analysis, the well established 11-year sunspot-cycle came to mind.

This cycle seems to have been discovered by Schwabe as long ago as 1843, but it was the classical work of Schuster,[57] at the beginning of the present century, that placed the existence of the cycle beyond all doubt. The spottedness is usually expressed as the relative number—a figure obtained by an arbitrary formula—and by following out the variations in this figure from year to year it is possible to identify epochs of maximum and minimum solar activity. Since the minimum of 1755 there have been 16 complete cycles, the average interval from one maximum to the next being 11.13 years. It should be noted that the minima do not necessarily fall midway between the maxima or vice versa. Indeed the intervals between maxima and minima tend to be longer than the succeeding intervals between minima and maxima. Further, the intervals between successive maxima or minima are not constant, varying from 8-15 years. The increase in solar spottedness since the minimum of 1933 has been one of the most spectacular ever recorded, and the maximum of 1938 is exceptionally high. According to a recent paper by Sanford,[58] there seems little doubt that the frequency of sunspots is influenced by planetary configurations, especially the configurations of Venus and the Earth.

The relationship between epidemics and solar spottedness is represented diagrammatically in Fig. 2, in which

the outbreaks are plotted as deviations from the nearest year of maximum spottedness. A diagram of this kind is a valuable method of revealing at a glance, the range and association of our observations, especially if they are not very numerous. The conspicuous feature of the diagram is the tendency of the outbreaks to cluster about, or slightly precede, the years of sunspot-maxima, i.e. approximately

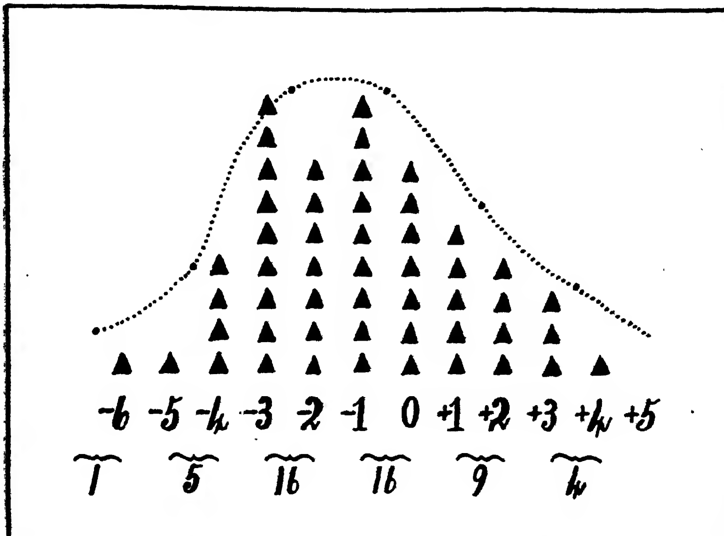

Fig. 2.—Relationship between Insect Outbreaks and Epochs of Maximum Solar Spottedness.

during the epochs of maximum spottedness. To be more precise, the majority of these insect-epidemics occur during the 5-year interval which commences three years previous to the sunspot-maximum and ends one year after it. For this ‘ optimum ’ 5-year interval, the difference between the actual and the expected distribution (on the basis of random chronological distribution of epidemics) is no less than 26.1 per cent—a highly significant figure. Moreover, a glance at Table VIII shows that each species has its own particular phase-relationship to the maximum, varying

from *Euxoa* at one extreme to Ague at the other; thereby indicating the variety of ecological conditions presented by the environment at different phases in the cycle of solar spottedness. While one would not expect all species to respond in the same way to fluctuations in the numbers of sunspots, an explanation of this *trend* towards mass-periodicity, in addition to a distinct periodicity in different species, must be sought in some general climatic pulsation, associated with the periodicity of sunspots.

	Range (—4 to 0)	Range (—3 to +1)	Range (—2 to +2)
Ague	5 out of 9=55.5%	6 out of 9= 66.6%	6 out of 9=66.6%
Ceraptéryx	5 ,, ,, 8=62.5%	7 ,, ,, 8= 87.5%	7 ,, ,, 8=87.5%
Tipula	9 ,, ,,10=90.0%	10 ,, ,,10=100.0%	7 ,, ,,10=70.0%
Phyllotreta	5 ,, ,, 8=62.5%	5 ,, ,, 8= 62.5%	5 ,, ,, 8=62.5%
Plutella	7 ,, ,, 8=87.5%	5 ,, ,, 8= 62.5%	4 ,, ,, 8=50.0%
Euxoa	5 ,, ,, 8=62.5%	4 ,, ,, 8= 50.0%	3 ,, ,, 8=37.5%
Average (%)	70.0	71.5	62.0
*Expected Aver.	45.4	45.4	45.4
Difference (%)	24.6	26.1	16.6

*On the Basis of Random Chronological Distribution of Epidemics.

Table VIII. Analysis of Epidemics in the Three 5-Year Intervals of Maximum Frequency.

This involves certain difficulties, since the influence of solar activity on terrestrial affairs is not yet completely understood, and the spottedness has different effects in different parts of the world. Indeed, it is only within recent years that unmistakable evidence has been adduced concerning the influence of the sun's cycle of activity on polar lights, movements of the compass needle, and radio-transmission; but these proven associations between changes in the sun (accompanying the outbreaks of sunspots) and the electrical state of the Earth's atmosphere, constitute the strongest available argument regarding the influence of solar spottedness on terrestrial affairs. Several investigators have endeavoured to trace the relationship between sunspots and weather phenomena, so that there is now an enormous literature on the subject, and, unfortunately, many conflicting results. Over thirty years ago, Clough[59] stated that in North America "periods of maximum solar activity are followed 7-10 years later by terrestrial temperature minima, and six years thereafter by rainfall maxima." Clayton,[60] who has spent a lifetime investigating the relationship between sunspots and atmospheric changes, draws the following general conclusions. The meteorological changes known as weather have their origins chiefly in the variations of solar radiation, but on account of the complexity of weather phenomena and their susceptibility to a variety of environmental effects, the exact relationship is difficult to define. On the whole, solar radiation is higher at sunspot-maxima, than at minima, and with increasing solar radiation, certain regions of the earth show opposite changes to each other. Thus, in the north and south temperate zones, temperatures are distinctly lower at sunspot-maxima, but in the arid subtropics temperatures are slightly higher at sunspot-maxima than at the minima. Similarly, while the rainfall over the eastern half of the United States is lower at epochs of maximum spottedness, it is actually 10-20 per cent higher over the North Atlantic, Africa, India and Australia.

Another investigator who firmly believes that weather phenomena have their origin in changes in the sun's radiation is Dr. C. G. Abbot,[61] of the Smithsonian Institution, Washington. By means of an instrument called a pryheliometer, Abbot has found that the mean value of the intensity of solar radiation is equivalent to 1.94 calories per square centimeter per minute, and that this "solar constant" sometimes varies to the extent of 4 per cent. The quality and intensity of solar radiation as received at the Earth's surface, are of course greatly modified, both by solar disturbances and phenomena of absorption and refraction. Further, Abbot[62] finds that the variations in weather comprise at least 12 periods, of which a 23-year period is of dominating importance in terrestrial weather responses to solar influences. Incidentally, this is also the approximate length of Hale's solar magnetic cycle. Various phenomena dependent on weather show the influence of the 23-year cycle, including the level of the river Nile, the rainfall of New England, the thickness of Eocene varves, and the abundance of cod and mackerel. Finally, as a result of the researches of Pettit,[63] at the Mount Wilson Observatory in California, it is now fairly well established that the intensity of the ultra-violet light varies with the number of sunspots, being considerably stronger during epochs of sunspot-maxima. So much for the relationships between sunspots and meteorological phenomena.

Regarding the effects of solar spottedness on organic responses, the extensive researches of Douglass[64] have revealed a striking correlation between the growth-rate of trees and the sunspot-cycle, both in America and in Europe. There is also little doubt that the connecting link between these two variables is climatic, although it has not been possible to obtain a *good* correlation between tree-growth and any *single* climatic factor (Antevs).[65] This is not unexpected, however, since the continual well-being of a tree requires the mutual interaction of

several factors at nearly optimum intensities, and any one factor in the ever-changing environmental complex may act in a limiting capacity, thereby leaving its impress upon the growth of the tree. And so it is with the growth of animal-populations in Nature; one year there may be insufficiency of heat to stimulate the physiological processes of reproduction; another year excessive drought may desiccate a large percentage of the eggs; and so on. Occasionally, *all* the essential factors are present in nearly optimum amounts, at the critical stages in the life-cycle, (i.e. stages of which the normal physiological functioning can proceed only within a very restricted range of environmental conditions), and the population assumes the characteristics of a 'plague.' On the basis of what is known concerning the effects of solar spottedness on terrestrial weather, and speaking in broad terms of climate, the writer is prepared to venture the following possible explanations of the undoubted association between sunspots and insect-epidemics in Britain.

IV. INTERPRETATION OF THE PHENOMENA.

The first is that the five-year interval, so favourable to insect-increase, occurs between the extremes of weather, when conditions are neither too cold and wet, nor too hot and dry, but warm and humid. This favourable period occurs when the sunspot-curve is approaching its maximum, but is followed by a period of low temperatures, as a result of which insect-populations are thinned out. Hardly have they had time to recover when they are subjected to the hot, dry conditions, during the epoch of sunspot-minimum. However, when the sunspot-curve commences to rise again towards its maximum, favourable climatic conditions return, and insect-populations may attain the dimensions of a 'plague.' This interpretation of the mass-periodicity is presented diagrammatically in Fig. 3., to which the reader is referred as aid to the verbal description.

Analysis of the table compiled by Nicholas and Glasspoole[66] (Monthly Rainfall over England and Wales, 1727-1931) reveals that there is actually a difference of 8.2 per cent between the June and July rainfall for the three years previous to sunspot-maxima and the corresponding rainfall for the three years previous to sunspot-

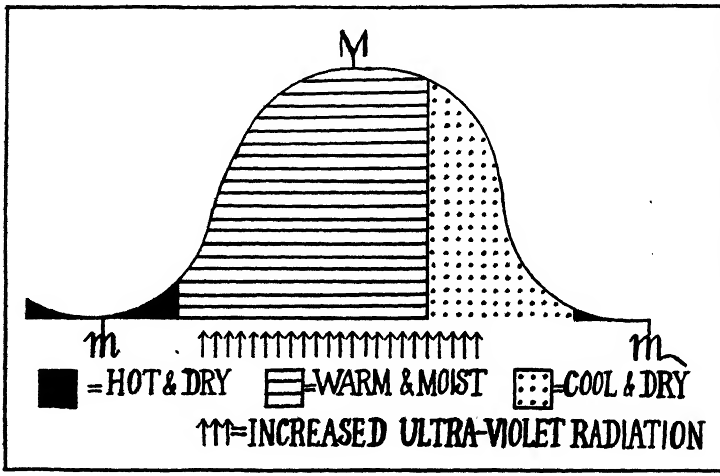

Fig. 3.—Climatological Interpretation of the Relationship between Sunspots and Insect Outbreaks.

minima; or, if the rainfall for June be considered alone, the difference is 12 per cent. The adverse effects of low temperatures and droughts, upon insect-populations, are well known to every economic entomologist, and several excellent examples are recorded by Uvarov[67]. These serve to emphasise the significance of rainfall in relation to the above explanation of the periodicities. Indeed, it seems that, so far as insect-plagues in Britain are concerned, rainfall is a factor of greater significance than temperature.

The other tentative explanation is that the epidemics may be associated with little known factors concerning the quantity and quality of solar radiation, especially in relation to the physiological effects of different wave-

lengths. Flint and McAlister[68] have definitely shown that, in germinating plant-seeds, the violet-blue light promotes a set of physiological processes quite different from the set which is promoted by orange-red light; and it was shown by Gal,[69] as long ago as 1898, that the growth of silk-worms and the number of eggs laid by the resulting adults are greater under violet light than under normal light. It appears, therefore, that different wave-lengths have markedly different effects upon the reproductive and other physiological processes of insects, and recent investigations emphasise the importance of the shorter wave-lengths. Now, as already indicated, the researches of Pettit have shown that the epochs of sunspot-maxima are attended by an increase in the energy of the shorter waves, i.e. the blue parts of the solar spectrum are considerably strengthened. The actinic properties of these rays have long been realised although not completely understood, and they may operate either directly upon the organisms or through their food-plans, e.g. by effecting an increased vitamin-content in the latter. There is still much to be discovered regarding the importance of the ultra-violet rays in relation to the all-important vitamins and the controlled functioning of hormones.

Perhaps neither of these explanations is adequate in itself, but the truth may be found in a modified combination of both, for it must be borne in mind that the insect is a more sensitive climatic integrator than any known meteorological instrument. That is to say, the organic response of the insect is a result of the combined operation of the whole climatic complex, and it is sometimes (not always) difficult to isolate a particular factor as playing the dominant rôle in the adducment of the response. Hence, an increased population is the integrated result of a particularly favourable combination of meteorological factors operating during the critical phase or phases in the life-cycle. These 'critical' phases are usually associated with reproduction or the early stages of existence (MacLagan).[70] Whatever the ultimate cause (and the

writer's belief is that rainfall and sunshine are the factors of predominating importance) there is little doubt of the reality of this mass-periodicity of major insect-outbreaks in Britain; and this means, oddly enough, that the modern science of ecology is able to confirm the findings of one of the oldest sciences, namely, meteorology.

In conclusion, it must be apparent that this investigation has revealed a complicated pattern of diverging roads beckoning for further exploration. Obviously, the next step is the climatological delineation of the conditions favourable to the increase of particular species, and it is difficult to imagine a more fertile field for bio-mathematical studies. In addition to the academic interest of the results, particularly in relation to the equilibrium of Nature, they would have considerable economic value, by providing a scientific basis for the *prediction* of outbreaks.

SUMMARY:

An historical study of the outbreaks of several British insects during the last hundred years or so, has been made. On epidemiological grounds it has been established that in Britain the frequency of outbreaks is correlated with the periodicity of sunspots. The years of maximum frequency are not exactly synchronous with epochs of sunspot-maxima, although nearly so. The connecting link between sunspots and outbreaks is climatic, the favouring circumstances being probably increased humidity and more intense ultra-violet radiation. As opposed to the views of several ecologists, the writer maintains that Darwin's phrase 'balance of Nature' is justified, since animal-populations not only respond to pulsations of the physical environment, but the response is governed by the whole natural controlling complex in a manner such that animal-populations *tend* towards stability, even if the stable density is never attained and indeed varies from place to place and from time to time. The investigation would appear to have opened up a fertile field for bio-mathematical study, in relation to the equilibrium of natural populations.

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CONTEMPORARY ENGLISH SPEECH

By Harold Orton, M.A., B.Litt.

(A Lecture delivered before the English Seminar of Berlin University on January 29th, 1939).

In England to-day the pronunciation of English has become a national topic. Probably never before has the question of right pronunciation been discussed with greater enthusiasm or vehemence. People are continually asking, "Is it correct to pronounce the *h* of *wh* at the beginning of words, (e.g. in *white*)," and "Is it right to leave out the *r* at the end of words and before a second consonant." But the most provocative question of all is: where is the best English spoken? These are only a few of the questions that correspondents keep on asking editors of our daily newspapers. Controversy only ceases with the editor's laconic announcement: this correspondence must now cease. Moreover the British Broadcasting Corporation's announcers are vigorously criticized for their pronunciation, though by no means so frequently as hitherto. Complaint is made, to my mind without justification, of their alleged effeminate voices, their clipped, stilted articulation, their abominable Oxford accent, whatever that may mean, and their mis-pronunciations. A few months ago, after a recent broadcast to schools, in which I referred to the excellences of the announcers' pronunciation, a lady sent me a letter of very sharp reproof. In this she flatly denied my statements and went on to express her amazement that the present announcers were able to keep their jobs, so unsuitable were they for them. Even in insignificant country villages the speech of the unfortunate B.B.C. announcers may be violently abused by people who are otherwise good-natured, and whose normal speech is homely dialectal English. Such strictures, coming as they do from wholly unqualified critics, might be ignored, perhaps even ridiculed, were it not that they are perfectly sincere, and obviously inspired both by a deep interest in their mother-tongue and by an ardent desire to hear the best English.

This comparatively recent growth of popular interest in spoken English is a welcome sign of the times. Not so many years ago our academic leaders were lamenting the Englishman's indifference to the study of his mother tongue, particularly in its historical aspects. In censuring this neglect, they could not fail to point to the enthusiasm, the thoroughness and ingenuity with which our language was studied abroad, and especially so in Germany. How greatly English Philology is indebted to German scholars becomes revealed to every student already on the threshold of his career; and he soon learns to honour their famous names.

Yet this newly awakened interest in English speech can hardly be attributed to the reproaches of our university teachers of about two generations ago. Rather, the stimulus appears to have indirectly come from the B.B.C., and more especially through its announcers. Since the inception of broadcasting, the B.B.C. has given to anyone who cares to listen, the chance of hearing English spoken in all its many types and varieties. From all quarters of the British Isles, as well as from distant parts of the globe, spoken English of all kinds has been poured into the homes of rich and poor up and down the country. Almost daily the listener can hear the simple speech of the provincial, the more sophisticated accents of the townsman, and the cultivated pronunciation of the speaker of Received Standard English, especially of the B.B.C.'s announcers. Inevitably the listener begins to compare his own particular brand of English with what he hears through his radio set. Comparisons stimulate criticism. Criticism stimulates interest. Interest, in its turn, may produce enthusiasm for the mother-tongue.

How far the B.B.C.'s influence upon English pronunciation is for the good is an oft debated question. Roughly speaking, there are two schools of opinion. To the first, perhaps much the more numerous group, belong the educationists. To them the problem seems

fairly simple: the B.B.C. provides first-class examples of how to speak the best kind of English; and they believe that the announcers and other good speakers are worth imitating by all who wish to improve their own ability to speak. The second group comprises those whom we may perhaps call the sentimentalists. The sentimentalists would preserve our English dialects at all costs. They love them for their alleged homely intimacy, for the friendliness that they seem to exhale. Now the vast majority of the sentimentalists are well-educated people. But local dialect seems to unbalance them, to upset their sense of proportion. Many of them themselves speak the most cultured English, and furthermore know one or two foreign languages. But they want the dialects preserved for other people to speak, not for themselves. Rarely will you come across a sentimentalist amongst those whose dialectal speech is their ordinary means of communication. As a rule, such people try to drop their local accents whenever they come into contact with strangers, for they are by no means happy about them. Not long ago, during one of my dialect-hunting expeditions in Northumberland, a small farmer, descendant of a family that had lived upon the same farmstead for some three hundred years, interrupted my questions about his pronunciation and said in the broadest dialect: "You know, I'm not giving you what I say. I'm just telling you what the lowest of the low say." That remark reveals little sentiment for provincial English. "The most honest defence of the retention of dialect," writes one of our leading English psychologists,[1] "comes from those who bluntly disbelieve in democracy, regard the existence of upper and lower classes as desirable, and Standard English as a passport purchasable at a high rate, to strata of society which are financially and socially profitable." Nowadays in England, a good pronunciation is everywhere accounted the mark of a good education and of a good upbringing; and a satisfactory speech behaviour is required of everyone that

seeks advancement in his profession. As Professor Lloyd James, the B.B.C.'s linguistic adviser, has said: "It is easier for the camel to pass through the eye of a needle, than for the child who speaks broad Cockney to pass into the Higher Civil Service or to become a shop assistant in a smart West End shop."[2] A swindler, with any pride in his vicious occupation, would forbear to dupe his victim in the simple utterances of provincial England; his stock-in-trade would more likely include an attractive voice, the most courteous speech, the most persuasive diction, and of course, an Oxford accent.

By now you will have gathered how important, in my opinion, is the B.B.C. as a factor in determining the present trend of English pronunciation in all its many varieties, but more especially of Rec. St. E. It is by far the strongest influence of the times. What then, it may be asked, is the B.B.C.'s official attitude to English speech? Does it set itself up as an authority? Does it attempt to prescribe the rules of pronunciation and to impose an arbitrary standard of English speech? No, it does none of these things. Its official attitude to these matters was laid down ten years ago by its former Director-General, Sir John Reith, who wrote as follows: "Since the earliest days of broadcasting, the B.B.C. has recognised a great responsibility towards the problem of spoken English. There had been no attempt to establish a uniform spoken language, but it seemed desirable to adopt uniformity of principle and uniformity of pronunciation to be observed by announcers with respect to doubtful words. The policy might be described as that of seeking a common denominator of educated speech."[3] Previously the B.B.C. had taken action as follows. In 1926 it set up its Advisory Committee on spoken English, a committee of scholars and laymen, to advise the Corporation in certain matters of English pronunciation. Two years later it issued its first booklet, *Broadcast English I,* containing its Committee's "Recommendations to announcers regarding

certain words of doubtful pronunciation." Presumably it also took steps to ensure that its announcers both abided by these rules, and maintained the highest possible standard of speaking. In 1934 this Committee was reconstituted and enlarged, and its procedure was modified to secure, amongst other things, the co-operation of the general public. It boldly invited the public to criticise the recommendations of the Committee. But its attitude to a standardised speech remained the same as hitherto. In his Introduction to the third edition of the same booklet, the Committee's Secretary, Professor Lloyd James, wrote: "The B.B.C. has no desire to accept or to dictate any standard of pronunciation other than the current usage of educated speakers." Note carefully the phrase, "the current usage of educated speakers." Now there are many to-day who look forward to the time when the "current usage of educated speakers" will receive official recognition from our educational pundits. Some of them may feel that the B.B.C. might even go so far as to outline the characteristics of that kind of English which it regards as the "current usage of educated speakers." But there are difficulties. For one thing, the B.B.C. is not a branch of the Board of Education, but curiously enough, comes under the responsibility of the Post-Master General. In any case, the Board of Education does not lay down the rules: it merely recommends, and its advice may be accepted or ignored by our local education authorities. So it seems that for the present we must accept the situation. We must wait; and meanwhile derive contentment from the fact that the B.B.C. almost invariably provides announcers whose speech exemplifies to many people's entire satisfaction the "current usage of educated speakers." Anyone who wishes to cultivate a good English accent can do no better than imitate them. The announcers are models of the best English usage.

It is time to pass from the general to the particular and turn to several features of Modern English that for

various reasons seem to have some special interest of their own. I shall deal with a few of our vowel and consonantal sounds and the changes that seem to be affecting them to-day; and I shall point out as well certain phonetic features that are not usually mentioned in English books on our language. These include one or two sounds that occur in dialectal English. The consonants may be dealt with first, for they are more easily followed. I may begin with *wh-*, e.g. in *whisper, while, whistle*.

I do not know what sound German students are usually taught to pronounce for our English *wh-* at the beginning of words. Presumably they are told that the O.E. parent sound viz. (hw) or the like, has regularly become (w) in the South, whereas in Scotland and the North of England it might survive, or become (f) or else (w). To-day in Rec. St. E., therefore, *wh-* regularly denotes the sound (w). Yet more and more people tend to insert the *h* and pronounce these words with (hw). Of course, this is no novelty in good usage. Thirty years ago, Professor Horn noted that the tendency had already set in under the two-fold influence of Northern English and the spelling.[4] This (hw)-type seems to be spreading rapidly, especially amongst the younger generation. Young people seem to say to themselves: look at the spelling; see, there's an *h* there; we must certainly pronounce it. And they do so. Nevertheless, and naturally enough, the "advanced speakers" include still more advanced speakers. The latter are apparently not wholly content with (hw), but they insist upon having a completely unvoiced *w*, viz. the highly 'refaned' (ʍ). As if to counterbalance this, Northern English, and especially the local dialects of the North country, appear to be moving in the opposite direction. Here, the (w)-pronunciations are spreading at the expense of the (hw)-type. This specially applies to the N.E. of England. So far as my observations go, natives of the county of Durham, speakers of both regional dialect and Modified St. E., invariably pronounce *wh* as (w),

i.e. without the *h*. So do Tynesiders as well. In South-East Northumberland, however, only words in unstressed positions seem to be at present affected. Thus here we find (hw) in *whip, whispers,* etc., but (w) in unstressed *what* and *which*. Confirmatory evidence of the extensive use of (w) for O.E. *hw-*, M.E. and Mod.E. *wh-*, in the North will be found in the monographs upon individual Northern dialects published since Joseph Wright issued his *English Dialect Dictionary* (1896-1905).

The sounds represented by the letter *r* deserve mention. In the parent A.S. language, the letter *r* is commonly thought to have stood for a trilled or rolled sound, viz. (r). But since then, it has undergone very considerable change. Nowadays in England, this consonant is never trilled, not even, despite current opinion, in the North of England.[5] The vast majority of English people are in fact, quite unable to make this trilled (r). In Rec. St. E., the *r* is pronounced only before vowel sounds; and the normal sound is merely a weak fricative (ɹ). Again, before consonants, this *r* has totally disappeared. For which reason, English people are often sternly censured by Scots and Irishmen alike for mispronouncing our language. But many of them will also tell us that no Englishman can speak English properly; the best English, they say, is spoken in Scotland or in Ireland, according to the nationality of the critic. So the Englishman persists in his alleged slovenly habit: he continues to use a fricative (ɹ), not the trilled (r), and also to leave out the *r* before a following consonant, even though he must face additional criticism from teachers of elocution and singing, so-called purists, spelling-pronunciation addicts, and others.

In Northumberland and parts of N. Durham, i.e. in the extreme North-East corner of England, the letter *r* has a very special sound, which is unparalleled in other parts of the British Isles. It is not, of course, an extraordinary sound, for it is found, though in a slightly different form, in France, Germany and Scandinavia. This is the

velar (ʁ). We give it a special name and call it the Northumbrian burr. The first record of its use in Northumberland dates from 1724-6, when it is mentioned by Daniel Defoe.[6] Some writers would trace it back as far as Shakespeare's time, without, however, wholly reliable evidence.[7] The sound has been variously described hitherto, and several observers have stated that it is a sound produced by vibration of the uvula against the back of the tongue.[8] Whilst this may have been the case in the past, the present sound is certainly not normally a rolled consonant. So far as I can judge, there seems to be three varieties. Firstly, a fricative (ʁ), in which the air-passage is narrowed at the back of the mouth so as to produce friction. Secondly, a fricative with the same tongue position but pronounced with rounded lips, thus producing a (w)-effect. This occurs before back-round vowels, e.g. in *room*, (ʁʷɔk), *rock* etc. Thirdly, there is a flapped (R), with one or two taps of the uvula against the back of the tongue. The latter is usually used for emphasis and often after (k) and (g). So far—and I have been all over the region concerned—I have not heard the rolled velar (R), which is so frequent in France, Germany and Scandinavia.

One other point in connection with the occurrence of *r* may be noticed, namely its pronunciation in the group *r* plus the so-called dental consonants *t, d, n, s, l*. As is well known we do not here pronounce this *r* in such a group in Rec. St. E. But the point of special interest is this: that many English people from all over England do not here pronounce the *t, d, n, s, l* in the ordinary way. They do not articulate these sounds with the point of the tongue touching (or in the case of *s*, close to) the teeth-ridge or alveoli. Instead they pronounce the corresponding retroflex consonants. That is, they pronounce the sounds with the point of the tongue actually touching, or close to, the junction of alveoli and hard palate. Thus many English people, including speakers of acceptable English too, distinguish between the pronunciation of the two *t's*

in *cat* and *cart*; and the *d*'s in *bid* and *bird*; the *n*'s in *can* and *corn*; the *s*'s in *cease* and *course*; and the *s*'s in *cause* and *boars*. These retroflex consonants have only previously been noted, I believe, in the Cumbrian dialect of Lorton[9] and in certain dialects south of the Thames[10]. The sounds in question are regular features of the present dialects of Northumberland. In Scottish-English, too, they are extremely prominent, the amount of retroflexion apparently being greater in the north than in the south.[11]

English people who are beginning the study of the German language have often much trouble with two consonants in particular, namely the *ch* in *ich*, and the *ch* in *Buch*. With one of these sounds, the trouble as a rule becomes chronic, and the learner may ultimately remain content to use his English (ʃ)-sound; so German *ich* becomes Anglo-German " ish." But the difficulty of your *ach-laut* (like *ch* in Scots *loch*) is apparently overcome, and the (x) is ultimately reproduced fairly comfortably. What surprises me, however, is this: It is precisely the German sound that many English people normally use at the beginning of words like *human, hew* that causes the greater trouble, while the other sound, (x), is a novelty to almost all English people.

Formerly this (x)-sound was common in Old English. Moreover it survived intact into Middle English, but gradually in the Modern Period of English became extinct. But in Scotland, the sound is a marked feature of present-day Scots dialect. Comedians from North Britain realise this; in fact, any Scottish comedian who failed to make play with this (x)-sound before an English audience would risk condemnation as an impostor. But be that as it may. What I want to emphasise is this, and I mention it here because it will have a particular appeal to Professor Horn, who almost forty years ago made the history of the English " Guttural Consonants " his own special field of study.[12] The (x)-sound is popularly supposed to have disappeared in England. Yet it was certainly used by a few speakers

of Yorkshire dialect within living memory. This information was given to me only recently by an elderly woman of 75, herself an excellent natural speaker of Yorkshire dialect. I met her at Todmorden, a town on the border separating South-West Yorkshire from Lancashire. She was introduced to me as being a most likely person to talk in and about the local dialect, for she was bred and born in the district, and had lived at Todmorden since girlhood. She told me that she well remembered people in that neighbourhood pronouncing words like *rough*, *enough* and *tough* with (x), which she herself pronounced easily and with great vigour. Similar information was given me by other elderly dialect-speaking natives of Todmorden, who pronounced the consonant without the slightest difficulty.[13] All this I thought was extremely interesting, because not many students of Historical English seem to know that this ancient Teutonic sound has lingered on in England until but yesterday.

Here we must leave the consonants, for the vowel sounds have their interest too, especially I think, those that show present signs of much instability. Firstly, I may mention one or two Rec. St. E. changes that are due to the vagaries of fashion, rather than to unconscious processes.

Amongst the older generation words like *cloth*, *cross* and *off* are very often pronounced with a long vowel as in *caught*, viz. (ɔ:). The words concerned are those which formerly contained M.E. *o* followed by *s*, *f* and *th*. Not all these words had this long (ɔ:)-sound, but most monosyllables had. Thus our seniors say, e.g. *broth*, *cloth*, *cross*, *frost*, *froth*, *loss*, *off* with (ɔ:); and also perhaps *offer*, *officer* and *possible*. But to the ears of many of the younger people, these hoary and most respectable (ɔ:)-pronunciations, dating from the seventeenth century, seem rather ridiculous and are tabooed. They prefer to pronounce these words with a short *o*, as in *pot*. This is not a sound change, but a sound substitution. However,

the corresponding long (*a* :) before the same consonants, e.g. in *path, glass, chaff,* is firmly entrenched in present-day speech. In fact the ordinary man regards it as one of the principal characteristics of the best English. It is also one of the major differences between Rec. St. E. and Northern English, in which these words are regularly pronounced with a short vowel. Any speaker of Northern English who wants to display his knowledge of Rec. St. E. will invariably do so by echoing pronunciations like (p*a*:θ, gɹ*a*:s, *a*:ftə).

Change in fashion seems also to be responsible for the reinsertion of the (j)-sound after *l* in words like *lute, lewd, lunatic,* etc. In 1926, Fowler noted that the popular change of (lju :) to (lu :) in such words had "gone too far to be now stemmed."[14] According to him, it was useless to attempt to retain the (j) here, because popular feeling disliked it. Nevertheless, since B.B.C. announcers and other good speakers frequently use these (lj)-pronunciations the fashion may be taking on a new lease of life. Thus (j) to-day is commonly inserted in e.g. *absolute, allude, allure, illumination, resolute.* But if the *l* is preceded by another consonant, e.g. in *blue, slew,* the once fashionable (j) will remain suppressed, perhaps because such *l*-forms are frequent in dialectal English.

Words spelt with *or* (e.g. *short*) and with *our* (e.g. *course*) present historians of the language with a series of very difficult problems. In these words historical changes seem to have resulted in the long vowel (ɔ:), or the diphthong (ɔ·ə), or else the variant (o·ə); thus (ʃɔ:t, kɔ·əs, ko·əs). For foreign students of English, the difficulty is to remember when to use the long vowel and when to use a diphthong. But the point is now scarcely worth bothering about, since to-day the long vowel seems infinitely more common, especially among young people.[15] Incidentally, many of them seem here to prefer a raised type of (ɔ:)-sound. Our long (ɔ:) is in process of becoming a half-close vowel.

The diphthong in words like *pay* and *came* is nowadays particularly unstable. While its first element is rather variable, the second element often totally disappears. Thus if *James came on pay-day* were pronounced ('dʒɛːmz 'kɛːmɒn'pɛːdɛː), it would sound quite normal to many excellent speakers, for many of them here drop the second element and say (ɛː) for (ei). If, however, it were pronounced ('dʒeːmz 'keːmɐn 'peːdeː), the speaker would be immediately classed as a North-countryman.

The diphthongs (ai) and (*a*u) in *mind* and *mound* respectively seem also to be losing their second elements. Thus ('ɹaːt mɪ ə 'laːn ə tuː) is not unusual to-day, nor does (wen aːm 'd*a*ːn 't*a*ːn aːl faːnd 'aːt) occasion much surprise. Of course the reduced forms of these diphthongs are often carefully distinguished; thus *find* may be (faːnd), but *found* becomes (f*a*ːnd). Similarly *tire* may become (ta˙ə) or even (taː), but *tower* becomes (t*a*ːə) or (t*a*ː), which latter, however, is distinguishable from *tar* (tɑː). To the ordinary student, these things seem rather involved, but here in Berlin, in the Phonetic Laboratory of this famous University, the question of phonetic change and its psychological causes is being studied with uncanny insight and skill. The results already achieved are no less impressive in their importance than they are astonishing. It is indeed a privilege to pay tribute to the phonetic investigations of Professor Horn and Dr. Ketterer, and to offer my very sincere wishes for the continued success of their work, and the work of their enthusiastic students.

Lastly I can hardly refrain from including a reference to the influence of the spelling on our pronunciation. A case in point is the *oor* in the everyday words *poor* and *moor*. The pronunciations (pɔː, mɔː) appear to be rapidly becoming antiquated, and are being supplanted by (puə) and (muə). Despite the existence of *door* and *floor*, the fact that double *oo* ordinarily stands for an (uː)-sound seems to weigh heavily in favour of (puə) and (muə). The abandonment of the (ɔː)-sound in favour of (uə) reminds

one that a similar change is affecting words ending in *ure*. To many people pronunciations like (ʃɔː, pjɔː, kjɔː, sɪ'kjɔː) for *sure, pure, cure, secure* seem to savour too much of the Victorian era and they accordingly prefer (ʃuə, pjuə, kjuə, sɪ'kjuə), or even (ʃɜː, pjɜː, kjɜː sɪ'kjɜː)

So I come to the end of this sketchy survey of Contemporary English Speech. In it I have touched upon one or two not generally known phonetic features of present-day English, and also referred to some of the unstable qualities of the best current usage. Some of the latter, I have ventured to designate as fashionable and others as obsolescent. I have also stressed the newly awakened interest of thousands of English people in their mother-tongue, an interest that seems to me indirectly attributable to the B.B.C. Possibly some would regard this as an overstatement, but since the Corporation pours spoken English of the best possible type into the homes of people throughout the length and breadth of the country, and at all hours of the day, it seems bound to happen that more and more people will in time learn to appreciate good speech, will endeavour to imitate it, and will ultimately speak it. If ever this country sets up an official standard form of English, the credit will almost certainly be in large measure due to the stimulating influence of the B.B.C.

FOOTNOTES.

1 T. H. Pear, *The Psychology of Effective Speaking*, 1933, p. 89.

2 *Our Spoken Language*, 1938, p. 161.

3 See his *Foreword* to *Broadcast English* I, by A. Lloyd James, 1928 etc.

4 Cf. *Historische Neuenglische Grammatik*, 1908, § 177. The author, the distinguished Professor of English at Berlin University, introduced me to the Seminar.

5 *Pace* D. Jones, *Outline of English Phonetics*, 4th Ed., 1934, § 751.

6 See his *Tour through the Whole Island of Great Britain.* Cf. also R. O. Heslop, *Transactions of the Yorkshire Dialect Society*, Pt. V, 1903.

7 Cf. also R. O. Heslop, *Northumberland Words*, E.D.S., 1892, pp. xxi-xxv, and refs.

8 E.g. A. J. Ellis, *Early English Pronunciation*, Pt. V, 1889, pp. 641-4; J. Wright, *English Dialect Grammar*, 1905, § 295.

9 B. Brilioth, *Grammar of the Dialect of Lorton*, § 38, 46, 53.

10 A. J. Ellis, *On Early English Pronunciation*, Pt. V, pp. 1455, 1473.

11 For an additional note on this topic see *Le Maître Phonétique*, No. 67 (1939), pp. 40-41.

12 *Beiträge zur Geschichte der englischen Gutturallaute*, 1901.

13 Cf. also A. H. Smith, "English Dialects" in *Trans. of the Philological Society*, 1936, p. 77, who also mentions the existence of (x) in words like *clough*, as well as *night*, in the dialect of Crag Vale, Upper Caldervale—roughly the same district as Todmorden.

14 *Modern English Usage*, pp. 335-6.

15 Cf. D. Jones, *Outline of English Phonetics*, 1934, § 458.

NOTEWORTHY PLANTS FROM GREAT AND LITTLE BERNERA (LEWIS), PABBAY AND BERNERAY (HARRIS), AND THE UIG DISTRICT OF LEWIS.

BY

W. A. CLARK, B.Sc., Ph.D., and J. HESLOP HARRISON.
(Dept. of Botany, King's College, Newcastle upon Tyne).

Last summer the work for the preparation of our County Flora of the Inner and Outer Hebrides was continued as vigorously as ever and on this occasion the main expedition concentrated its efforts on the Barra Islands and on the parts of S. Uist not visited during the previous year. As a result of this work several new plants have been added to the Flora of the Outer Islands and in three cases to the Flora of Scotland. In addition to the main expedition, however, a small advance party visited the Uig district of Lewis and the islands of Great and Little Bernera (Lewis), Pabbay (Harris) and Berneray (Harris) which could not be tackled by the larger party owing to transport and other difficulties. The present paper places on record the more important plant finds of this expedition.

Of the islands visited, Berneray proved to be the most exciting from the botanical standpoint and here interest was chiefly confined to the machair in the west. This area provided us with *Draba incana* L., *Arabis hirsuta* Scop., *Juncus balticus* Willd., *Carex maritima* Gunn. (*C. incurva* Lightf. f. *erecta* O. F. Lang.), and the rare hybrid orchid, *Orchis latifolia* L. sec. Pugsley × *Coeloglossum viride* (L.) Hartm., while the two parents, particularly the Frog Orchis, were exceedingly abundant. In fact our most vivid impression of these dunes was of Frog Orchis.

The colour of the flowers of the latter varied enormously, all shades between light yellow and dark purple being observed. It was in a batch of these orchids, collected to show this range in colour, that Prof. J. W. Heslop Harrison identified the hybrid and his identification was later confirmed by Mr. Patrick Hall.

Special mention must also be made of the Uig dunes for here we found two alpines, *Silene acaulis* L. and *Polygonum viviparum* L., growing literally at sea level, well within reach of the spray. The former was also noted on the sea cliffs near Aird Uig, and the latter on the dunes of Little Bernera. Miss Campbell in a recent paper[1] records *P. viviparum* from the Uig sands, stating that it is new to Lewis. We would like to point out however, that the Uig station for this plant was recorded in an earlier paper[2], a copy of which was sent to the British Museum. Lastly, Great Bernera provided us with another interesting sedge which Mr. Nelmes has identified as *Carex Hudsonii* A. Benn.

The researches described in this paper were rendered possible by a grant from the Research Committee of King's College (University of Durham), and to them we tender our thanks. In conclusion we would also like to thank Messrs. Pugsley, Nelmes and Dandy, Dr. G. Taylor, and Prof. J. W. Heslop Harrison for help with critical genera.

1 Journal of Botany, Vol. LXXVIII, April 1940, pp. 101-102.
2 Proc. King's College (University of Durham) Agricultural Students' Association, Vol. VI, Parts III and IV, December 1939, pp. 20-23.

Arabis hirsuta Scop.
On grass covered rocks near Uig Village, and on grassy hillocks on the machair, Berneray.

Draba incana L.
Along with *Arabis hirsuta* on the dunes, Berneray.

Cochlearia groenlandica L.
Fairly common on sea cliffs, Great Bernera, Pabbay and Berneray.

Silene maritima With.
Locally common on sea cliffs, Aird Uig (Lewis), Geodha nan Calman (Great Bernera), Little Bernera and Pabbay.

Silene acaulis L.
Quite common at points along the shore of Uig Bay and also on the sea cliffs, near Aird Uig.

Ilex aquifolium L.
On cliffs, Glen Valtos (Lewis).

Geranium molle L.
On the dunes near Valtos Village, Lewis.

Ulex europaeus L.
Noted at several points along the road from Stornoway to Uig and again at Callanish (Lewis).

Trifolium dubium Sibth.
By the roadside, near the burial ground, Uig.

Vicia sepium L.
First of all noted on a rubbish heap near Tobson, Great Bernera, but later also observed quite commonly among Bracken covered rocks at the foot of cliffs on the same island; also recorded from Little Bernera.

Lathyrus pratensis L.
Usually on cliffs and recorded from Uig, Great and Little Bernera.

Lathyrus montanus Bernh.
On ledges of cliffs, Glen Valtos (Lewis), and on sea cliffs, Uig Bay; also not uncommon on shaded cliffs Great and Little Bernera.

Rosa canina L. (agg.)

Lutetianæ group.

(a) Var. **lutetiana** Baker. Cliffs, Tobson and near Sandavat, Great Bernera; Little Bernera.

(b) Var. **senticosa** (Ach.) Baker. A form best referred to this variety, Loch Ruig, Great Bernera.

Transitoriæ group.

(c) Var. **spuria** Pug.
(1) f. **syntrichostyla** Rip. Great Bernera.

Dumales group.

(d) Var. **dumalis** Bechs.
(1). f. **viridicata** Pug. Cliffs near the ferry pier, Great Bernera.

(e) Var. **Carioti** Chab. Shores Loch a' Chnuic, Great Bernera.

(f) Var. **sylvularum** Rip.
  (1) f. **adscita** Déségl. Shores Loch Baravat, Great Bernera.

R. glaucophylla Winch (agg.)

Reuterianæ group.

(a) Var. **Reuteri** (God.) H. Harr. Valtos and Glèn Valtos, Lewis; Loch Baravat, Breaclete, and Croir, Great Bernera; cliffs in the east of Little Bernera. The form on Little Bernera was noteworthy for its small leaves.

(b) Var. **subcristata** (Baker.) H. Harr. Shores Loch Baravat, Great Bernera.

R. Sherardi Dav. (agg.)

(a) Var. **typica** W.D.
  (1) f. **submollis** Ley. Hacklate and cliffs near the pier, Great Bernera.
  (2) f. **pseudomollis** Ley. Shores of Loch Baravat, Great Bernera.
  (3) f. **uncinata** Lees. A form very near this but not quite typical, cliffs, Tobson, Great Bernera.
  (b) Var. **suberecta** (Ley.) H. Harr. Cliffs of South Earshader near Hacklate, Great Bernera.
  (c) Var. **Cookei** H. Harr. Cliffs in the Croir district of Great Bernera. This is a considerable extension of the known distribution of this endemic rose.

Sorbus aucuparia L.
Cliffs, Glen Valtos (Lewis), and Great and Little Bernera.

Sedum roseum Scop.
On the cliffs, Glen Valtos (Lewis), and quite common on sea cliffs, Aird Uig, Geodha nan Calman (Great Bernera), Little Bernera, and Pabbay.

Hippuris vulgaris L.
In a streamlet running into Loch Bhruist, Berneray.

Epilobium parviflorum Schreb.
Wet areas near the shore in the north of Berneray.

Apium nodiflorum Reichb.
In ditches and wet areas of the dunes, Pabbay; also in the streamlet running into Loch Bhruist, Berneray.

Apium inundatum L.
Wet areas Uig and Valtos dunes (Lewis), and in similar places on Pabbay and Berneray. On Great Bernera it was observed in a small moorland lochan near Sandavat, right off the dunes where it normally occurs on the islands.

Ligusticum scoticum L.
On the shore, Uig Bay, beside the *Silene acaulis;* sea cliffs, Geodha nan Calman, Great Bernera; sandy beach, Little Bernera, and on sea cliffs, Pabbay.

Hedera Helix L.
On the cliffs, Glen Valtos (Lewis), and on sea cliffs near the ferry pier, Great Bernera.

Lonicera Periclymenum L. var. **Clarki** H. Harrison.
Noted on the Glen Valtos cliffs (Lewis), and in similar places on Great and Little Bernera.
Solidago Virgaurea L.
Cliffs, Glen Valtos and Aird Uig (Lewis) and Croir, Great Bernera.
Tanacetum vulgare L.
Usually beside habitations, Uig and Valtos (Lewis), Callanish (Lewis), and Tobson (Great Bernera).
Aster Tripolium L.
On shores of Loch Borve, Berneray, but plants very dwarf.
Antennaria dioica Gaertn.
Recorded from all the islands and often noted growing at sea level.
Tussilago Farfara L.
Only recorded from the dunes, Pabbay.
Petasites ovatus Hill.
Quite common at Uig, Aird Uig, and Valtos (Lewis); also recorded from Little Bernera, Pabbay and Berneray.
Crepis capillaris Wallr.
On dry turf dykes, Uig, and Callanish (Lewis).
Hieracium iricum Fr.
Cliffs on the dunes in the east of Little Bernera.
H. scoticum F.J.H.
Cliffs, Valasay district of Great Bernera.
H. argenteum Fr.
Cliffs near the pier, Great Bernera.
Taraxacum laevigatum DC.
On the dunes, Uig, Little Bernera, Pabbay and Berneray.
Vaccinium Myrtillus L.
Another of the plants found on the cliffs, Glen Valtos, and also recorded from Pabbay.
Arctostaphylos Uvi-ursi Spreng.
Cliffs, Glen Valtos, Lewis, and on the shores of Loch Baravat, Great Bernera.
Samolus Valerandi L.
On a wet clayey exposure on the north shore of Berneray.
Myosotis repens G. and D. Don.
On the shore of Loch Breaclete, near Breaclete Village, Great Bernera.
Lithospermum arvense L.
Quite common on the dunes and old cultivated areas, Valtos, Lewis.
Veronica agrestis L.
Old fields, Uig, Lewis.
Veronica scutellata L.
Marshy ground near Hacklate, Great Bernera.
Veronica Anagallis-aquatica L.
Wet areas of machair, Uig and Valtos (Lewis), Pabbay and Berneray.
Euphrasia brevipila Burnat and Gremli. f. **subglandulosa** Bucknall.
On the dunes, Uig, Lewis.

E. nemorosa (Pers.) Löhr. near var. **collina** Pugsl.
On the dunes, Uig, Lewis.

E. confusa Pugsl. f. **grandiflora.**
Glen Valtos, Lewis.

E. curta (Fr.) Wettst.
Hacklate, Great Bernera. A glabrescent form was also collected from the dunes of Little Bernera.

E. scotica Wettst. var. **purpurascens** Pugsl.
Glen Valtos, Lewis.

E. micrantha Rehb.
Breaclete, Great Bernera.

E. Campbellae Pugsl.
Breaclete, Great Bernera.

Pinguicula lusitanica L.
Shores of Loch Baravat, Great Bernera; Little Bernera, and Pabbay.

Scutellaria minor Huds.
Glen Valtos, Lewis, and shores of Loch Baravat, Great Bernera.

Stachys palustris L.
On a wet area in the village, Berneray, and also at Callanish, Lewis.

Teucrium Scorodonia L.
Glen Valtos, Lewis.

Suaeda maritima Dum.
Shores of Loch Borve, Berneray.

Polygonum viviparum L.
At sea level, on the shore, Uig Bay, and again on the dunes, Little Bernera.

Myrica Gale L.
Rare and only recorded from Glen Valtos, Lewis.

Corylus Avellana L.
Cliffs on the shore near Glen Valtos, Lewis; quite common on sheltered cliffs, Great Bernera, and also recorded from Little Bernera.

Populus tremula L.
Glen Valtos cliffs, Lewis, and similar habitats, Great and Little Bernera.

Listera ovata Br.
A number of plants observed in the pasture in front of Uig Lodge, Uig Bay, Lewis.

L. cordata Br.
In Sphagnum, under Heather, Glen Valtos, Lewis, and in similar situations round the shores of Loch Baravat, Great Bernera.

Orchis latifolia L. sec Pugsl. × **Coeloglossum viride** (L.) Hartm.
A specimen of this rare hybrid, new to Britain, was discovered by Professor J. W. Heslop Harrison among a batch of Frog Orchids collected from the machair in the west of Berneray. The range of flower colour observed among the Frog Orchids has already been commented upon in the introduction.

Orchis mascula L.
Grassy cliffs, Uig Bay, Lewis.
Scilla verna Huds.
On grass covered rocks near the village, Uig, and again on the sea cliffs, Aird Uig.
Juncus balticus Willd.
On wet areas of the dunes, Valtos (Lewis), Pabbay and Berneray. On Pabbay some of the plants attained a height of 2 feet.
Luzula sylvatica Gaud.
Glen Valtos and Aird Uig, Lewis; shores and Dun, Loch Baravat, Great Bernera.
Lemna minor L.
In a wet area near the village, Berneray.
Potamogeton natans L.
Loch Sgailler, Valtos, Lewis; Berneray.
× **P. nitens** Weber.
Little Loch Borve, Berneray.
P. crispus L.
Loch Bhruist and Little Loch Borve, Berneray.
P. Berchtoldii Fieb.
Little Loch Borve, Berneray.
P. pectinatus L.
Little Loch Borve, Berneray.
× **P. suecicus** Richt.
Little Loch Borve, Berneray.
Scirpus setaceus L.
Marshy ground, Glen Valtos, Lewis, and Pabbay.
S. maritimus L.
In ditches near the beach, Tobson, Great Bernera.
Carex maritima Gunn. (C. **incurva** Lightf., f. **erecta** O.F.Lang.)
Observed in a few wet hollows of the machair in the west of Berneray.
C. Hudsonii A. Benn.
On the moor near the pier, Great Bernera.
C. Goodenowii Gay. var. **juncea** Fr.
Croir district in the north of Great Bernera.
C. limosa L.
Glen Valtos, Lewis; small loch beside Sandavat, Great Bernera and in a bog, Little Bernera.
C. pilulifera L.
Glen Valtos, Lewis.
C. distans L.
Uig, Lewis.
C. Hostiana D.C. × **C. demissa** Hornem.
Moor Hill, Berneray; near Loch Heddal More, Pabbay.
C. demissa Hornem.
Uig and Glen Valtos, Lewis; Little Bernera; Moor Hill, Berneray, and Pabbay.
C. subglobosa Mielichh.
Glen Valtos, Lewis; Loch a' Chnuic, Great Bernera.

C. lepidocarpa Tausch.
Glen Valtos, Lewis.

Alopecurus pratensis L.
Only observed at Callanish, Lewis.

Phleum pratense L.
In old fields, Uig, Lewis,

Aira caryophyllea L.
Common in the cultivated fields, Uig, Lewis, and on grassy slopes near the village, Berneray.

Deschampsia caespitosa Beauv.
Only observed in the shelter of a stone dyke on the roadside between Callanish and Breasclete, Lewis.

D. setacea Richter.
Quite common round the margins of several lochs on Great Bernera viz. Loch Ruig, Loch a' Chnuic, and small lochan near Sandavat; also observed in a small loch near Loch Heddal More, Pabbay. Since we discovered this grass in the summer of 1938 on North and South Uist, it has been recorded from practically all the islands we have visited.

Catabrosa aquatica Beauv.
Wet areas of the dunes, Uig, Lewis; on the shore near the landing place, Pabbay, and near Loch Borve, Berneray.

Dactylis glomerata L.
Uig, Lewis; Breaclete, Great Bernera, and Callanish, Lewis.

Poa palustris L.
Marshy ground, among Irises, Valtos, Lewis; Berneray, and Callanish (Lewis).

Brachypodium sylvaticum Roem and Schult.
A few plants were observed on sheltered ledges of cliffs near Bosta beach; Great Bernera.

Juniperus siberica Burgsdorf.
Glen Valtos, Lewis; shores Loch Baravat, Great Bernera; Little Bernera.

Hymenophyllum unilaterale Bory.
In the shelter of Heather, Glen Valtos, Lewis and the shores of Loch Baravat; also recorded from Little Bernera.

Asplenium Ruta-muraria L.
Sandy cliffs on the dunes, Uig, Lewis.

Phegopteris polypoides Fée.
Sheltered ledges and caverns of the cliffs, Glen Valtos, Lewis.

Osmunda regalis L.
Exceedingly abundant round the shores of Loch Baravat, Great Bernera.

Ophioglossum vulgatum L.
Common on the dunes, Pabbay and Berneray.

Botrychium Lunaria Sw.
Recorded from all the islands dealt with in this paper.

Equisetum sylvaticum L.
Marshy, sheltered ground near Earshader, Lewis.

Lycopodium Selago L.
Only recorded from Pabbay.

A PHYSICAL ANALYSIS OF CERTAIN LAKE DEPOSITS.

By E. G. Richardson, B.A., Ph.D., D. Sc.

The distribution of particle size among natural sediments has recently become of importance for the geological and limnological studies of the chronological sequence of conditions which have accompanied the formation of the beds of lakes and of river courses. Krumbein[1], in particular, has shown how size: frequency curves and the other devices of statistical analysis may be usefully applied to sediments of this type.

The writer had recently the opportunity of applying the methods of mechanical analysis, by which a specimen of soil is grouped into fractions comprising specific ranges of particle size and the relative masses in each group expressed as percentages of the total mass or exhibited on a distribution curve, to some cores extracted from the beds of Windermere and Esthwaite Water. The extraction was carried out with the aid of special apparatus devised by Jenkin[2] and was of two types. The one machine drives a hollow tube into the consolidated bed of the lake and extracts a core in sections covering six metres without disturbing the relative location of the bottom deposits and thus affords a stratified section of the bed of the lake dating back to the ice age. This has been used in Windermere. The second type, used in Esthwaite Water, a much less deep lake, serves to remove a layer of ooze and mud from the top twenty centimetres of the bed, again without disturbance of the relative positions of successive layers in the deposit.

The author's apparatus[3] by means of which the size : frequency analysis is made works on the photo-electric

1 J. sediment. Petrol., 4, 65 (1934).
2 R. M. Jenkin and C. H. Mortimer, Nature, 142, 834 (1938).
3 J. agric. Sci., 84, 457 (1934); Trans. Ceramic Soc., 38, 359 (1939).

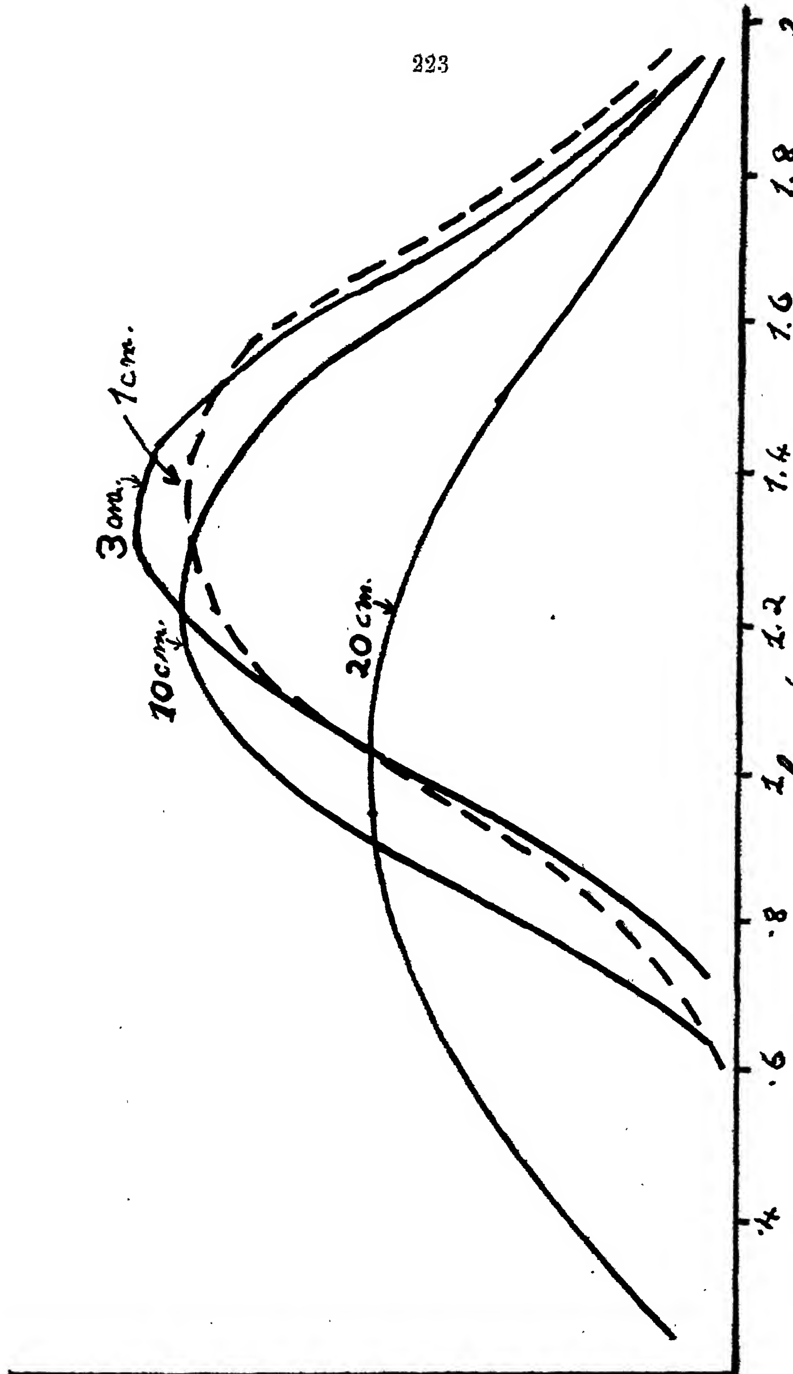

FIG. 1.

principle and has been fully described elsewhere. It gives the 'summation curve' for the specimen, on which ordinates represent the total surface of all particles having a diameter less than that of the abscissa over which they stand. From this the 'distribution curve' of the relative masses of particles having a specific diameter is derived by erecting tangents at selected points on the first curve. Two sets of these distribution curves are given, one for each of the lakes. The particle diameter (d) is measured in microns and it is actually plotted logarithmically (with reference to a base of 10) as abscissa, while the ordinates represent the relative masses of each diameter of particle found in the sample. The numbers attached to the curves denote the depth of the sample in centimetres and metres respectively below the top surface of the bed. The general form of the curves bears a similarity to the standard deviation curves of statistics but with a maximum (corresponding roughly to the mean particle size) shifted towards lower values as one samples at lower depths; in other words, the deposit gets finer as one digs further into the bed.

In the Esthwaite muds (Fig. 1), only recent depositions are represented. The whole extract is loosely compact and semi-fluid. The division of the conglomerate into finer particles at lower depths may be the result of chemical and bacterial action breaking down the aggregates which are formed of silt and organic detritus deposited upon the lake bed in the absence of circulating currents, or it may mean no more than that the finer particles during the natural process of sedimentation penetrate through the interstices between the larger crumbs in the ooze until they are brought to a standstill lower down. The change in mean particle size found in the samples is not directly proportional to the depth but increases slowly at first and then more rapidly. The change is nearly exponential, a fact that Krumbein[4] has noted in certain sediments on a beach at Wisconsin, U.S.A. Thus, if one plots the logarithm of the

[4] J. Geol. 45. 577, (1937).

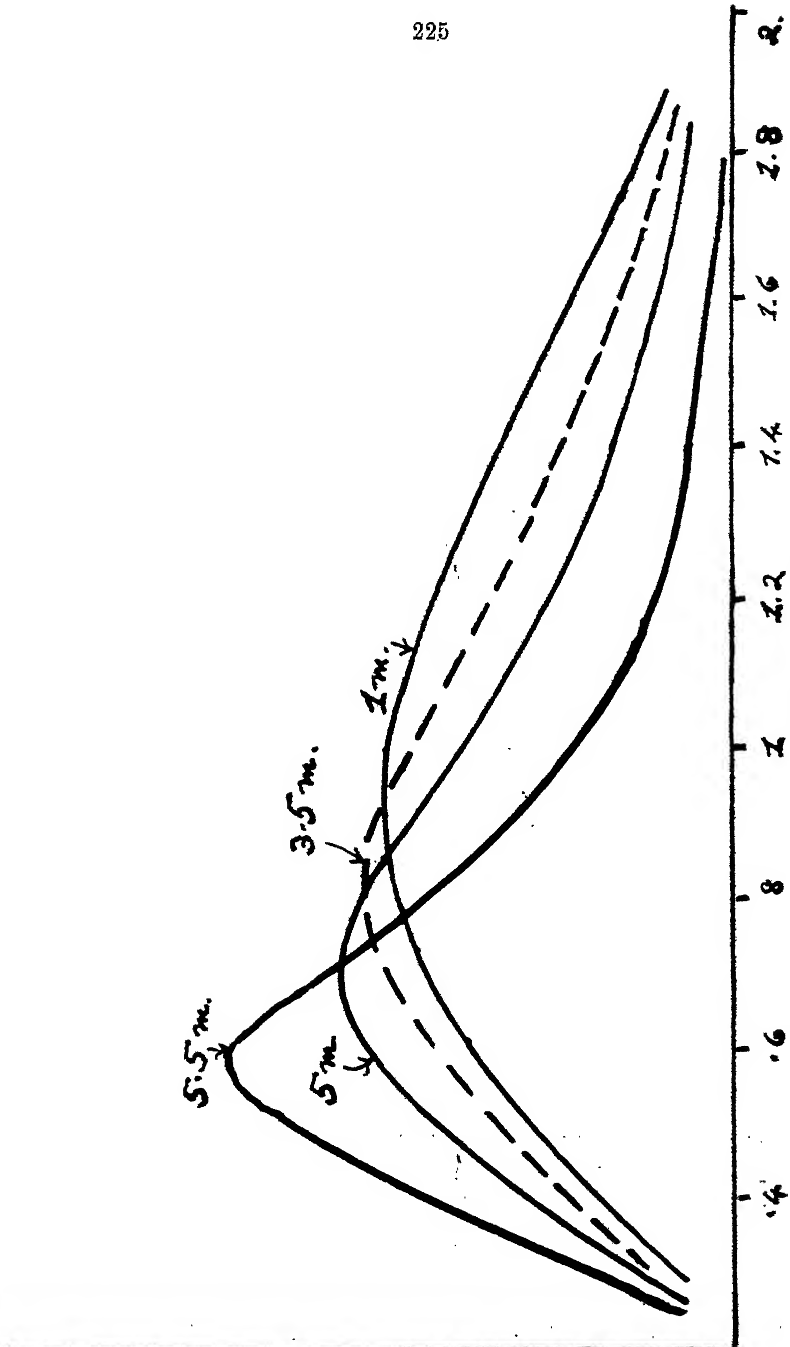

FIG. 2.

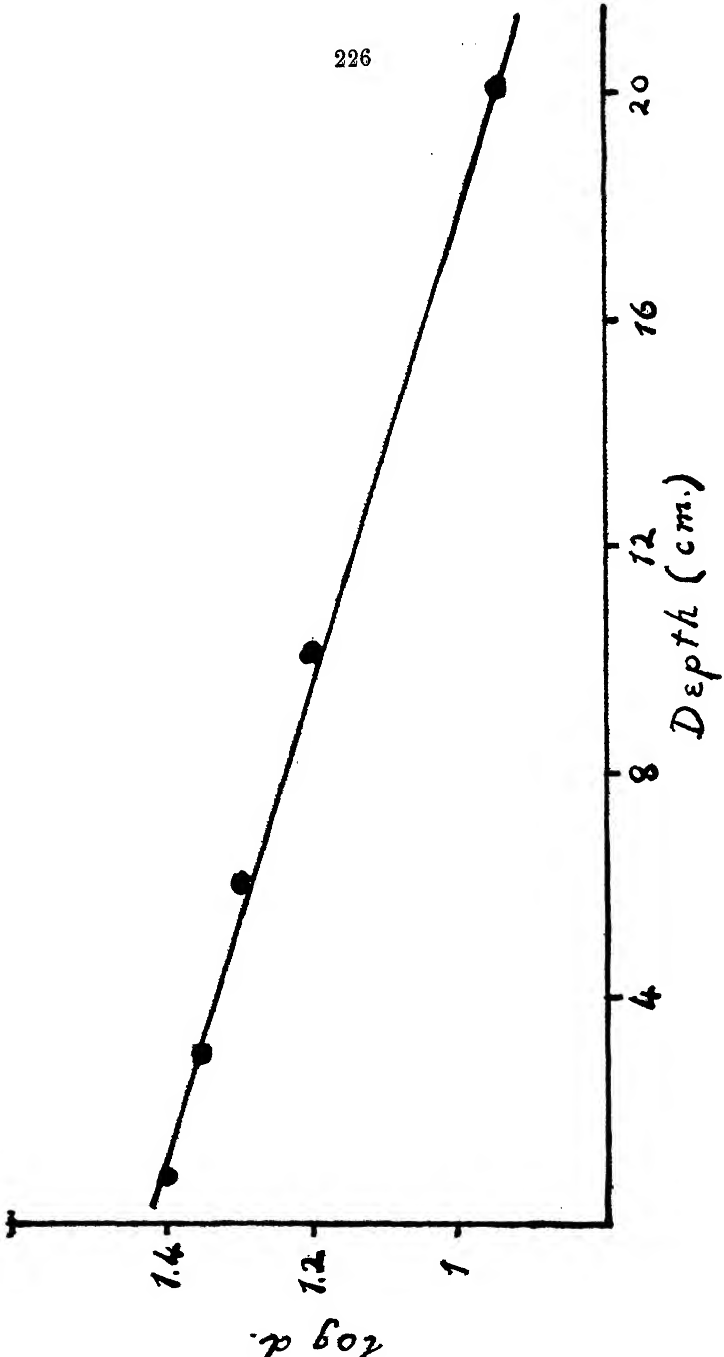

FIG. 3.

particle size having the peak mass value in Fig. 1 against depth of sample we get quite a good straight line (Fig. 3).

Such a law is not, however, found to satisfy the compact Windermere bottom deposits (Fig. 2) which represent centuries of bed formation. At the bottom of the core (5.5 m.) we find a pink clay which proved to be finer in texture than another clay taken from a glacier deposit in Norway. Above this the clay suddenly changes into a mass of humus and mud in a semi-hardened condition representing an intermediate stage between the surface mud and the fine silt brought down by glacier action ages before. The change is not however an uninterrupted progression. Bands of colour in the core and of clay between organic detritus may indicate geological catastrophes in the bed formation, or the seasonal inflow of silt from rivers in spate. Some of the samples which obviously held a considerable amount of organic material were analysed in the state in which they were found and also after heating to break down the organic substances. The result of the two analyses did not differ markedly, indicating that the ignitable material possessed the same mean particle size as the inorganic soil with which it was mixed.

These results are given to illustrate the application of 'mechanical analysis' to the study of sedimentary deposits, but it is not claimed that inferences of great import may be deduced from such analyses taken alone, but in conjunction with chemical and biological examinations of the same specimens they may lead to evidence of value for the life histories of the lakes in question. As Welch says in his text-book of Limnology; "There is great need for a critical study of bottom deposits." In such a study the physicist may take a not unimportant part.

These results were obtained during a stay at the laboratories of the Freshwater Biological Association at Wray Castle on the shore of Lake Windermere and the author wishes to express his appreciation of the help which he derived from illuminating conversations with the Director and his Staff on the subject of lake deposits.

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CONTENTS.

Fig. 1. Map of the Hebrides.

A PRELIMINARY FLORA OF THE OUTER HEBRIDES.

Edited by J. W. Heslop Harrison, D.Sc., F.R.S.

Although our survey of the Outer Hebrides is not yet finished and therefore the time for publishing our comprehensive Flora of the Inner and Outer Hebrides not yet ripe, in view of the present situation we think it well to assemble and put on record the results already obtained. These represent the labours of very many expeditions organized by, and dispatched from, the Department of Botany, King's College, University of Durham, during the six years 1935-1940. The series commenced by the examination of Barra and South Uist in 1935 and ended on the Isle of Benbecula in 1940. During the course of our investigations we have visited the whole of the major islands and many of the less important ones, including Lewis and Harris, Great Bernera and Little Bernera, (Lewis), Pabbay, Berneray and Taransay (Harris), North Uist, Baleshare, the Monach Isles, Benbecula, South Uist, Eriskay, Fuday, Fiaray, Barra, Vatersay, Flodday, Muldoanich, Sandray, Pabbay (Barra), Mingulay and Berneray (Barra).*

Collectively, this group of islands, often called the "Long" Island, forms the Watsonian Vice-County 110, and, as is well known, lies to the West of Scotland, being separated from Sutherland, Ross-shire and Skye by the Minch and the Little Minch. Geologically speaking, the formations represented in them are extremely uniform for the rocks encountered throughout the area investigated are of Lewisian age. Thus the types of habitat open to plants for occupation are of a very limited nature although they are eked out to some extent by the occurrence of extensive sand dunes, with the accompanying machair, composed mainly of shell sand. In spite of these limitations, the fruits of our researches have been exceedingly satisfactory, no fewer than 697 species, segregates in critical genera and hybrids having rewarded our efforts.

As was to be expected, the personnel responsible for investigations did not differ materially from that which took part in the Inner Island work. Once again we have to recognise the invaluable and almost indispensable assistance of Mr. R. B. Cooke whom we now look upon as an honorary member of the Department. Thus the following were not only responsible

*In the appended list the following contractions are often used for these names:—L., H., G.B., L.B., P.H., B.H., T., N.U., Bal., Mo., Ben., S.U., E., F., Fy., B., V., Fl., Mul., S., P.B., M., and B.B.

for the collection and study of the material now being discussed, but also for the preparation and publication of the present paper.

Professor J. W. Heslop Harrison, D.Sc., F.R.S.
Dr. K .B. Blackburn, F.L.S.
Miss E. Bolton, M.Sc.
Miss H. B. Bond, B.Sc.
Dr. W. A. Clark.
Mr. R. B. Cooke.
Miss H. Heslop Harrison, M.Sc.
Dr. G. Heslop Harrison.
Mr. J. Heslop Harrison.

However, the list of workers would be incomplete were the names of Mr. W. Campion and Dr. A. Ritchie omitted. Both afforded great help during the expeditions in which they participated.

Of the above, Prof. J. W. Heslop Harrison, as previously, made himself responsible for the Salices and Orchidaceæ, Prof. Heslop Harrison and Miss E. Bolton for the Rosæ, Dr. K. B. Blackburn for the Violaceæ and Charophyta and Miss H. Heslop Harrison for the Gramineæ. Further, Dr. W. A. Clark carried out the necessary researches on Mingulay and Berneray (B.), as well as on the Islands lying to the north of Benbecula; in the latter work he had the assistance of Mr. J. Heslop Harrison.

Naturally, these introductory remarks would be incomplete without our tendering well deserved thanks to those who have, in such a whole-hearted manner, aided in making our efforts a success. Amongst these, we have to place Mr. and Mrs. McIntosh of the School House, Stoneybridge, S. Uist in the forefront; our thanks to them could not be too strongly expressed. Other Stoneybridge friends were also unstinting in their efforts to assist us. Further, we must recognize the kindness of the Rev. Dr. Campbell, Bishop of Argyll and the Isles, and of Mr. J. Campbell, School House, Vatersay.

Moreover, for help of a different order, we have to thank the authorities of the Royal Botanic Gardens of Kew and Edinburgh. In addition, we must express our appreciation of the help given by various specialists who have so willingly named critical species for us, or have checked our determinations. Of these, Mr. G. M. Ash has examined the Epilobia,

Mr. H. W. Pugsley the Fumariæ, Hieracia and Euphrasiæ, Mr. E. Nelmes the Carices, Mr. P. M. Hall certain Violas, Dr. W. O. Howarth the Festucæ and Mr. W. Watson the Rubi.

Finally, to the Research Committee of King's College we give our warmest thanks; without their generous support the problems presented by the transport of ourselves and the necessary apparatus from island to island, and in securing temporary places in which to work would have been utterly impossible.

(Throughout this paper, we have, for the most part, adhered to the nomenclature of the 1939 " Flora of Devon " (edited by Rev. W. Keble Martin and Gordon T. Fraser), although we have, on occasion, not hesitated to exercise our judgment in the choice of name.

All plants representing new county records or considered noteworthy for other reasons are marked with an asterisk*).

THE LIST OF PLANTS.

RANUNCULACEÆ.

***Thalictrum alpinum** L. Alpine Meadow Rue.
Locally plentiful on the Beinn Mhor massif, S. Uist, and on cliffs and in gullies on Cnoc Eadar dá Bheinn, N. Harris.

T. arenarium Butcher. Sand Meadow Rue.
Frequent on sand dunes, the machair and often in cultivated fields on nearly every island: not observed on Fy., Muld., and Fl.

***T. montanum** Wallroth.
On cliffs, S. Harris, and on banks Benbecula, S. Uist.

Ranunculus trichophyllus Chaix.
Not uncommon in lochs on the machair, Bayhead, N.U., Mo., T., Valtos, L., P.H., B.H., E., B., and V. The variety, *Drouetii* F. Schultz seems less plentiful than the type on S. Uist, Barra and Vatersay.

***R. Baudotii** Godr.
As var. **marinus** (Fr.) near Borve, Benbecula.

R. hederaceus L. Ivy-leaved Crowfoot.
Bornish and Stoneybridge, S. U.; Borve, Barra; The Square and Coalis, Vatersay.

***R. sceleratus** L. Celery-leaved Crowfoot.
Frequent in marshy places in the west of Benbecula; rare near Loch Ardvule, S. Uist.

R. Flammula L. Lesser Spearwort.
Common in wet places on all the islands; var. *radicans* Nolte occurred near Lochboisdale, S. U., and near Loch St. Clair, Barra, and var. *angustifolius* Wallr. on Loch Eynort, S. Uist.

R. acer L. Common Buttercup.
Abundant on all the islands, even the spray-drenched Flodday; on S. Uist a glabrous mountain form is no doubt var. *pumilus* Wahl., whilst another, with finely cut leaves is var. *Boraeanus* Jord. On Fuday plants were seen with pale yellow flowers..

R. repens L. Creeping Buttercup.
More local than the last, but on all the islands except Fiaray and Muldoanich.

R. bulbosus L. Bulbous Buttercup.
Not uncommon and often sporadically abundant on the machair.

R. Ficaria L. Lesser Celandine.
Often common on rock ledges, under rocks, ravines, etc.; we have no Lewis or Benbecula records, but an early visit would reveal its presence there. Only the seed-bearing form was observed.

Caltha palustris L. Marsh Marigold.
Generally frequent in wet places but unrecorded for B.H., Mul., and Fl.

***C. radicans** L.
Quite rare; in the central area of S. Uist and the Uidh peninsula, Vatersay.

NYMPHAEACEÆ.

Nymphaea alba L. White Waterlily.
Abundant in some lochs; Lewis, North Harris, South Harris, Great Berneray, North Uist, Benbecula, South Uist, Eriskay, and Barra.

N. occidentalis Moss.
This has much the same distribution as the preceding.

PAPAVERACEÆ.

Papaver dubium L. Long Smooth-headed Poppy.
Occasionally in crops on all the inhabited islands; often very small.

FUMARIACEÆ.

***Fumaria Bastardi** Bor. Fumitory.
Never really common, but amongst crops on all the larger islands; also on roadsides on Barra and Taransay.

***F. Boræi** Jord.
Rare; near the village, Vatersay; Tangusdale, Barra; and Balevanish, Benbecula.

F. officinalis L. Fumitory.
Rather scarce on cultivated machair land and on the sea shore; South Uist, Barra and Eriskay. All the Fumitories from Lewis, Harris and the adjoining islands were *F. Bastardi*.

CRUCIFERAE.

Nasturtium officinale R.Br. Water Cress.
Sometimes common along streams and on wet ground in the machair; only seen on N.U., T., Mo., B.H., Ben., S.U., E., B., F., V., and P.B. The var.*siifolium* Reichb. occurred near Loch Altabrug, S. Uist.

***Arabis hirsuta** Scop. Hairy Rock Cress.
Rare and local on dunes and machair, etc.; Berneray (H.), grassy cliffs Uig, (L.), East dunes T., B., F., and Vatersay.

Cardamine pratensis L. Cuckoo Flower.
Not uncommon on moist ground on every island except Berneray (B.)

C. hirsuta L. Hairy Bitter Cress.
Not common, Uig, L., N.H, S.H., Mo., Bal., N.U., Ben., S.U. and M.; sometimes the plants fail to attain a height of an inch as on Baleshare and Benbecula.

C. flexuosa With.
Occasionally in shady places in Glen Valtos, L., N.U., T.; on all southern isles except E., P.B., F. and B.B.

***Draba incana** L. Hairy Rock Cress.
Locally frequent on the machair; Fuday and Berneray (Harris).

***Erophila Boerhaavii** (Van Hall) Dum.
Abundant on the sand-dunes at Sollas, N. Uist as var. *brachycarpa* (Jord.) O. E. Schulz.

***E. praecox** (Stevens) DC.
Quite common on the dunes on Baleshare.

Cochlearia officinalis L. Common Scurvy Grass.
Common along the coast; not, however, observed on Benbecula, Pabbay (B.) and Flodday.

***C. alpina** Wats. Alpine Scurvy Grass.
Rare and local on the cliffs on the north side of Beinn Mhor, S.Uist,

***C. danica** L.
Sandy places near the sea; N.U., Ben., S.U., V., S., and P.B.

C. scotica Dr. Northern Scurvy Grass.
Generally the commonest species on the coast of all the islands although we have no Lewis specimens.

Sisymbrium officinale Scop.
Rare on Lewis (Uig), B.H., Mo., Ben., S.U., E. and B. The var. *leiocarpum* DC. was detected on Barra and S. Uist.

***Subularia aquatica** L. Awlwort.
Rare in lochs near Stoneybridge, S. Uist.

Brassica Rapa L.
Often abundant on cultivated ground, Lewis, Berneray (H.), Benbecula, S. Uist and Barra. In S. Uist it occurs high on sunny cliff ledges in Glen Corodale far from habitation.

Sinapis arvensis L. Charlock.
Not a very abundant weed, but on all the cultivated islands.

Capsella Bursa-pastoris Medik. Shepherd's Purse.
Common in cultivated and disturbed land; not noted on Pabbay (H.), Baleshare and Little Bernera.

***Carara Coronopus** (L.) Medik. Swine's Cress.
A roadside weed, North Bay, Barra.

Cakile maritma Scop. Sea Rocket.
Local on sandy beaches, often very large and well grown; apparently absent from Mingulay and Berneray.

Raphanus Raphanistrum L. Wild Radish.
A weed of cultivation on most islands in the form of var. *aureus* Willm.

VIOLACEÆ.

Viola palustris L. Marsh Violet.
Sometimes quite plentiful in damp places on most islands; not observed on B.H., P.H., V., S., and B.B.

***V. sylvestris** Lam. Violet.
Very rare on the machair and near Loch Eynort, S. Uist and cliffs, East Loch Tarbert, Harris.

V. Riviniana Reichb. Violet.
The common violet of the islands from Lewis to Mingulay.

***V. canina** L. Dog Violet.
Scarce; behind the dunes, Bornish, S. Uist; Maari, N. Uist.

V. Lloydii Jord.
As a weed on Taransay.

V. Lejeunei Jord.
In rye on S. Uist.

***V. agrestis** Jord. var. **segetalis** Jord.
In sandy rye fields, and on land lying fallow; Benbecula and near Loch a'Mhoil, S. Uist.

V. obtusifolia Jord.
In rye etc., on Benbecula, S. Uist, Barra and Vatersay.

V. Curtisii Forster.
Locally plentiful on the machair and dunes from Lewis to Pabbay (B.).

POLYGALACEÆ.

Polygala vulgaris L. Milkwort.
Quite rare, its distribution not fully worked out; S. Uist, Eriskay, Fuday.

P. dubia Bellynck.
Frequent on all the islands; often as on Mingulay, Sandray etc., var. *dunensis* Dum. prevails.

*__P. serpyllacea__ Weihe.
Rather rare on peaty soils, Uig, Lewis, Harris, N.U., S.U., E., S., Mul. On Mingulay forms occur which are obviously the Hebridean guise of var. *vincoides* Chod.

CARYOPHYLLACEÆ.

Silene maritima L. Sea Campion.
Common on rocky coasts, but not seen on Benbecula, Eriskay, Fuday, Flodday, Berneray (Harris); found also on a shingle beach on the Monach Islands.

*__S. acaulis__ L. Moss Campion.
Very rare; Skate Point, Berneray (Barra), Hecla (Mingulay), at sea level Uig (Lewis) and on the cliffs, Ard Uig, (Lewis).

*__Lychnis alba__ Mill. White Campion.
Local, but sometimes not rare as at the Village, Eorisdale and Uidh, Vatersay; Eoligarry, Barra; Daliburgh and Kildonan, S. Uist.

Lychnis alba × L. dioica.
Found in rye on Vatersay.

L. dioica L. Red Campion.
Rare except on the east coast of S. Uist, where it makes red patches on the cliffs; also on Muldoanich.

L. Flos-cuculi L. Ragged Robin.
Very plentiful in damp places everywhere except on Baleshare, Flodday and Muldoanich.

Cerastium tetrandrum Curt. Sea Mouse-ear Chickweed.
Common enough in sandy places by the sea; fails in Fiaray, Muldoanich and the Monach Isles.

*__C. semidecandrum__ L.
On the machair, Baleshare.

C. viscosum L. Mouse-ear Chickweed.
Not uncommon, but only by paths etc., on the inhabited isles. Var. *elongatum* Dr. occurs.

C. vulgatum L. Common Mouse-ear Chickweed.
Common on every island; on South Uist from the sea-shore to the top of Beinn Mhor.

*__C. arcticum__ L.
Very rare on a cliff ledge on Rueval, Benbecula.

Stellaria media Vill. Chickweed.
Common on all the islands.

S. neglecta Weihe.
On road sides, S. Uist, Mingulay and Berneray (B.)

S. uliginosa Murr. Bog Stitchwort.
Often frequent in ditches etc., but absent from some of the smaller isles.

Arenaria serpyllifolia L. Thyme-leaved Sandwort.
Not really rare in dry places but not reported from Berneray, (H.), Baleshare, Fuday and Pabbay (B.)

Minuartia peploides (L.) Hiern. Sea Purslane.
Found on every island except Bal., Fy., S., Mul., Fl., and B.B.

***Sagina maritima** G.Don. Sea Pearlwort.
Local on rocky sea shores and spray-swept cliffs; Monach Isles, G.B., P.H., S.U., E., B., Fy., V., S. and Fl.

S. apetala Ard. Annual Pearlwort.
Rare; path on S. Uist.

S. procumbens L. Procumbent Pearlwort.
Common everywhere except on Baleshare. The var. *spinosa* was collected on Fuday.

S. subulata Presl. Heath Pearlwort.
Frequent at intervals on exposed rocky places, not usually near the coast; we have it from nearly every island from Harris to Mingulay.

S. nodosa Fenzl. Knotted Pearlwort.
In the northern isles detected on Ceann Ear in the Monach Isles, but failing only on the very small islands to the south of Benbecula.

Spergula sativa Boenn. Corn Spurrey.
Very abundant on cultivated ground from Lewis to Vatersay, also found on Taransay, the Monach Isles, Sandray etc.

Spergularia salina Presl. Sea Spurrey.
Usually plentiful in saltmarshes from N. Uist to Barra and Muldoanich.

S. marginata Kittel. Sea Spurrey.
Less frequent than the last, but in similar stations, Great Bernera; Loch Borve, Berneray (H.); Loch Maddy, N. Uist; Benbecula, S. Uist, Eriskay and Fuday.

***S. rupicola** Lobel. Rock Spurrey.
Very rare; only on the south of Loch Eynort, S. Uist.

PORTULACEÆ.

Montia fontana L. Water Blinks.
Plentiful in wet places on practically the whole of the "Long" Island as the var. *lamprosperma* Cham.

***M. verna** Necker. Blinks.
Very local on S. Uist near Daliburgh.

ELATINACEÆ.

***Elatine hexandra** DC. Waterwort.
Very rare in shallow lochs; Loch Ollay, S. Uist, Lochan nam Faoileann, Barra.

HYPERICACEÆ.

Hypericum pulchrum L. Beautiful St. John's Wort.
Very common on every island except the Monachs, Baleshare, Fiaray and Flodday.

***H. elodes** L. Marsh St. John's Wort.
In slow streams and bogs; Loch Eynort and north of Daliburgh, S. Uist; very rare behind Heaval, Barra; locally plentiful on Vatersay; rare, Gleann Mor, Sandray.

LINACEÆ.

***Radiola Linoides** Roth. All-seed.
Very local though abundant where it does occur; Eriskay, on S. Uist from Carnan Iochdar to Loch Eynort, and on Benbecula.

Linum catharticum L. Cathartic Flax.
Universally common on banksides etc., on all islands except Baleshare, Fiaray and Flodday.

GERANIACEÆ.

Geranium molle L. Dove's Foot Crane's-bill.
Frequent on sandy ground from Lewis to Pabbay (Barra).

***G. pusillum** L. Small-flowered Crane's-bill.
Very rare near Stoneybridge, S. Uist.

***G. dissectum** L. Cut-leaved Crane's-bill.
Very occasional, cultivated ground S. Uist and Barra.

***G. Robertianum** L. Herb Robert.
Very rare; Allt Volagir ravine and on the east coast near Loch Skiport, S. Uist.

Erodium cicutarium L'Herit. Stork's-bill.
Common on all the islands possessing dunes and machair from Harris to Pabbay (B.). In S. Uist it is sometimes to be found on sunny cliff ledges.

Oxalis Acetosella L. Wood Sorrel.
Rare in sheltered places at the base of cliffs and rocks; shores of East Loch Tarbert, Harris; North Lee, N. Uist; gorge on the east side of Rueval, Benbecula; Loch Eynort cliffs etc., S. Uist and near Loch Obe, Barra.

AQUIFOLIACEÆ.

***Ilex Aquifolium** L. Holly.
Cliffs south shore of East Loch Tarbert, Harris and Glen Valtos, Lewis.

ACERACEÆ.

Acer Pseudo-platanus L. Sycamore.
Well grown, planted trees near Brevig, Barra.

LEGUMINOSAE.

***Ulex europæus** L. Whin.
Noted on the road side from Stornoway to Uig also at Callanish, Lewis; Loch Minish, N. Uist; Loch Skiport and other points, S. Uist; and at several points in the east of Barra.

Cytisus scoparius Link. Broom.
Near the Manse, Tarbert, Harris; probably planted.

***Ononis repens** L. Rest Harrow.
Locally plentiful on the machair near Bagh a 'Deas, Vatersay; rare on Vatersay Bay.

***Medicago lupulina** L. Black Medick.
Rare between Stoneybridge and Howmore, S. Uist.

Trifolium pratense L. Red Clover.
Common on every island from Lewis to Barra Head save Flodday.

T. medium L. Zig-zag Clover.
Here and there; often on rock ledges, but nowhere common, Uig, Lewis; Great and Little Bernera, S. Uist, Eriskay and Barra.

T. repens L. White Clover.
Very common on the whole of the "Long" Island and its satellites; the var. *rubescens* Ser. on the machair, Vatersay.

***T. procumbens** L. Hop Trefoil.
Near Loch Altabrug, S. Uist.

T. dubium Sibth. Lesser Trefoil.
Rare in the north as at Uig, Lewis, but more frequent on the southern inhabited isles with Sandray in addition.

Anthyllis Vulneraria L. Kidney Vetch.
On practically every island in sandy ground; the var. *villosa* Corb. occurs in a very sturdy form on the Vatersay and Muldoanich cliffs and in a less luxuriant guise on S. Uist.

Lotus corniculatus L. Bird's-foot Trefoil.
Common on every island; exceedingly well marked examples of the var. *hirsutus* Rouy abound on the dunes on S. Uist and Fuday.

Vicia Cracca L. Tufted Vetch.
Of free occurrence on most of the islands including the rocky Muldoanich, with the var. *argentea* Coss. and Germ. on S. Uist and Vatersay.

***V. Orobus** DC. Bitter Vetch.
Very rare on sunny cliffs on the east coast of Eriskay.

V. sepium L. Bush Vetch.
Quite common amongst bracken-clad rocks on Great Bernera and Little Bernera; rare on cliffs on S. Uist, Eriskay, Barra, Sandray, Muldoanich, Pabbay (B.) and on Mingulay.

Lathyrus pratensis L. Meadow Vetchling.
Thinly distributed; Uig, Lewis, G.B., L.B., Ben., S.U., E., B., F., V., Mul., M., B.B.

***L. montanus** Bernh. Tuberous Bitter Vetch.
For the most part exceedingly rare, but, nevertheless, common on Great and Little Bernera; elsewhere on cliff ledges in Glen Valtos and on Uig Bay, Lewis and on cliffs on the north side of Loch Boisdale, S. Uist.

ROSACEÆ.

Filipendula Ulmaria (L.) Maxim. Meadow Sweet.
Generally abundant in low lying marshy ground, but most unaccountably absent from Benbecula; also missing in Baleshare, Monach Isles, Fiaray and Flodday.

Rubus idæus L. Raspberry.
Not common; amongst rocks on Benbecula; Loch Eynort, S. Uist, Allt Heiker, Barra and Sandray.

R. idæus × R. fruticosus (?).
On the lower slopes of Trinival, S. Uist.

R. fissus Lindl. Red-fruited Bramble.
Loch Eynort, S. Uist.

R. rotundatus Muell. ex Genev.
Brevaig, Allt Heiker, Barra; near the Monument, Benbecula.

R. imbricatus Hort.
Loch Skiport, S. Uist.

R. incurvatus Bab.
Market Stance, Benbecula.

R. oxyanchus Sudre.
Griminish, Benbecula.

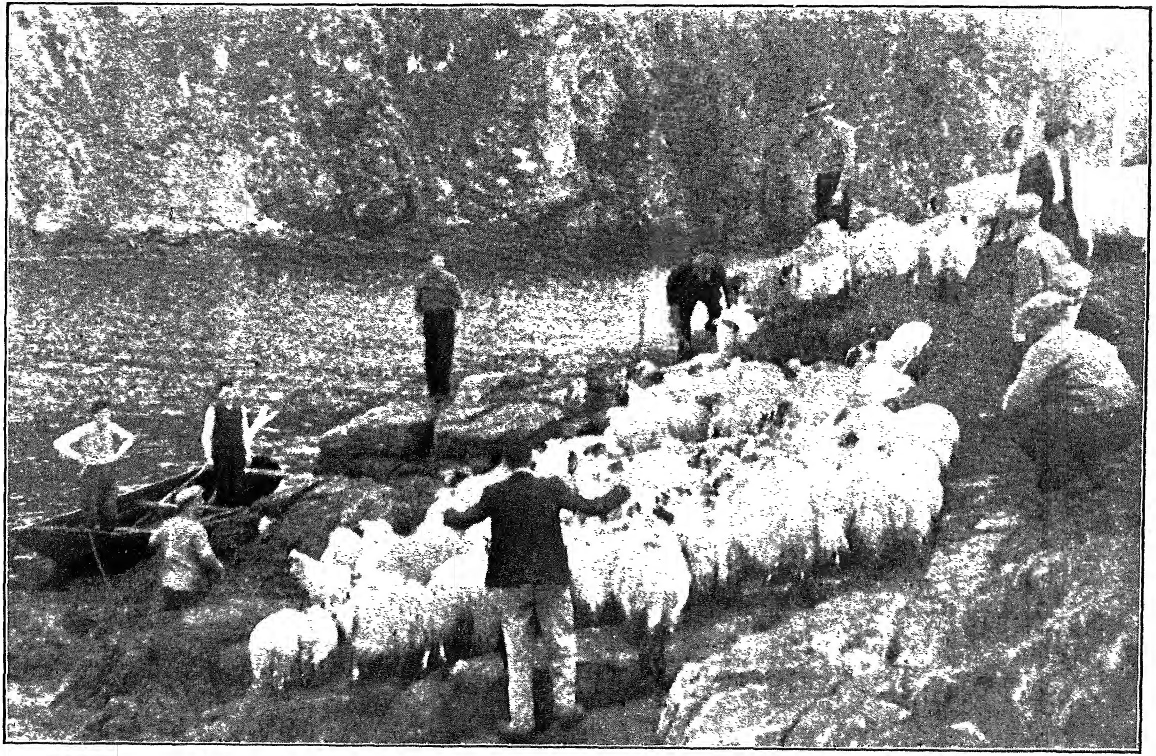
R. Scheutzii Lindeb.
Stream near Maola Breac, S. Uist.

R. dumnoniensis Bab.
N.E. of Barra; Maola Breac, S. Uist.

R. danicus Focke ex. Frid. and Gil.
Between Loch Eynort and Spin, S. Uist.

R. polyanthemus Lindeb.
Kyles Stuley, S. Uist, interesting as forming a phytogeographical link with Coll where this species is common.

R. Lindebergii P. J. Muell.
West of Bornish, S. Uist.



(*Photo. by J. Heslop Harrison*).

Fig. 2. A scene on Great Bernera and Little Bernera.

R. lasiothyrsus Sudre.
Scattered on North Uist; Loch Eynort, Lochboisdale, S. Uist, Allt Heiker, Barra; Vatersay Bay, Vatersay.

R. insularis subsp. **confinis** (Lindeb). Aresch.
Lochboisdale, S. Uist and Eriskay.

R. nemoralis P. J. Muell.
Craigastrome and Rueval, Benbecula.

R. thyrsoideus Wimm.
Lochboisdale, S. Uist.

R. ulmifolius Schott.
Base of Trinival, S. Uist.

R. Schlechtendalii var. **anglicus** Sudre.
Corodale and Loch Skiport, S. Uist.

R. iricus Rogers.
Northbay, Barra, near Loch Rigarry, S. Uist.

R. eupectus (Sud.) W. Wats.
Eriskay.

R. adenanthus Boul. et Gill.
On warm rock ledges north of Lochboisdale, S. Uist; one of the very southern plants found in the Hebrides.

R. mucronifer Sudre.
Lochboisdale, Loch Eynort, Bornish, Loch Skiport, S. Uist; Eriskay and in a gorge on Pabbay (B.).

R. rotundifolius Bab. ex Blox.
Moorlands near Loch Ba Una, Benbecula.

R. radula Whe.
Rueval, Benbecula.

R. Griffithianus Rogers.
Sea cliff opposite Isle of Wiay, Benbecula.

R. pallidus var. **leptopetalus** Rogers.
Northbay, Barra.

R. adenolobus W. Wats.
Pathside to Rueval, Benbecula.

R. rivularis var. **hirtiformis** Sudre.
Rocks near Ersary, Barra.

R. tenuiarmatus Ed. Lees.
Behind Ledaig, Barra.

R. althæfolius Bab. **non** Host.
Kildonan Glen, S. Uist.

R. conjungens Bab.
Path to Peter's Port, Benbecula.

R. Balfourianus Blox. ex Bab.
On a cliff in the centre of Sandray.

R. cæsius L. Dewberry.
Amongst bracken on the shores of the Dubh Loch, Benbecula. In view of the occurrence of the following hybrid on S. Uist this species must occur there; up to present. we have not detected it.

R. cæsius × **R. ulmifolius.**
On the path to Spin, S. Uist.

R. saxatilis L. Stone Bramble.
On Toe Head, Harris, cliffs on Loch Skiport and Eynort, S. Uist; Dubh Loch, Benbecula; gorge behind Loch na Doirlinn, Barra.

***Fragaria vesca** L. Wild Strawberry.
Very rare and local; only in the Allt Volagir ravine, and on ledges on the east coast, S. Uist.

Potentilla erecta (L.) Hampe. Tormentil.
Common everywhere on peaty soils except on the Monach Isles.

P. Anserina L. Silver-weed.
Common, and very often abundant near the sea; but not on Muldoanich. The var. *concolor* Wallr. is almost as plentiful as the type.

P. palustris (L.) Scop. Marsh Cinquefoil.
Locally common on all the islands except the Monachs, Pabbay (B.), Mingulay and Berneray (B.).

Alchemilla arvensis (L.) Scop. Parsley Piert.
Uncommon; Creagorry, Benbecula, Baleshare, and Stoneybridge, S. Uist.

***A. minor** Huds. Lady's Mantle.
Very rare on rocky slopes on the east coast of S. Uist. Var. *filicaulis* Buser occurs also.

***A. alpestris** Schmidt.
Locally common on the Beinn Mhor-Hecla group of mountains, S. Uist, but rare on Toe Head, S. Harris, Moor Hill, Berneray (H.), Barra and Vatersay.

***A. acutidens** Buser.
Very rare as var. *alpestriformis* C. E. Salmon on Hecla, S. Uist, also on Moor Hill, Berneray (H.).

***A. alpina** L. Alpine Lady's Mantle.
Only on the north side of the summit of Clisham, N. Harris.

***Agrimonia odorata** Mill. Agrimony.
Sparingly on cliffs on the north shore of Loch Boisdale and near Kyles Stuley, S. Uist.

R. canina L. Agg.

Lutetianae group.

(a) Var. **lutetiana** Baker. Little Bernera, Tobson and Sandavat, Gt. Bernera; Rueval, Benbecula; Corodale, S. Uist; Fuday and Ersary, Barra.
(b) Var. **sphaerica** (Gren.) Dum. Cliffs on west side of Corodale Bay, lower course of Allt Heiker, Barra.
(c) Var. **flexibilis** Déségl. Hellisdale, S. Uist, Fuday.
(d) Var. **senticosa** (Ach.) Baker. Untypical forms near Loch Ruig, Gt. Bernera.
(e) Var. **oxyphylla** Rip. Rocks, east coast of Barra.

Transitoriæ group.

(f) Var. **spuria** Pug. Cliff on Loch Eynort, S. Uist with plants near f. **syntrichostyla** on Gt. Bernera.
(g) Var. **globularis** Franch. Ersary, Barra.
(h) Var. **ramosissima** Rau. Inland cliff on Sandray.

Dumales group.

(i) Var. **dumalis** Bechs. Cliffs near Tarbert, Harris.
(1) f. **viridicata** Pug. Rocks near ferry pier, Gt. Bernera; coast north of Brevig, Barra.
(j) Var. **biserrata** Mer. Loch Skiport, S. Uist.
(1) f. **eriostyla** (Rip.) W.-Dod. Fuday and the east coast of Barra.
(k) Var. **Carioti** Chab. Shores or Loch a Chnuic, Gt. Bernera; Hellisdale and Loch Eynort, S. Uist.
(l) Var. **sylvularum** Rip. Streamside near Ersary, Barra.
(1) f. **adscita** Déségl. Shores of Loch Baravat, Gt. Bernera.

Andegavenses group.

(m) Var. **verticillacantha** Mer. A very poorly characterised form, nearest f. *agraria* (Rip.) W.-Dod., was found on cliffs north of Loch Boisdale, S. Uist.

R. glaucophylla Winch. Agg.

(a) Var. **Reuteri** (God.) H.-Harr. Valtos and Glen Valtos, Lewis; Loch Baravat, Breaclete and Croir, Gt. Bernera; cliffs on Little Bernera, Harris, Taransay, North Uist; Loch Skiport, S. Uist; Eriskay; Ersary, Barra; Muldoanich, Vatersay and Mingulay.

(b) Var. **subcristata** (Baker) H.-Harr. Not really rare; Loch Baravat, Gt. Bernera; Harris, N. Uist, Taransay; Lock Skiport, base of Mt. Hecla, Loch Eynort etc. S. Uist; Eriskay; lower slopes of Heaval, Borve, etc. Barra; Muldoanich, Vatersay and Mingulay.
   (1) f. **jurassica** (Rouy) H.-Harr. Loch Skiport, S. Uist; Brevig, Ersary, Barra.
   (2) f. **myriodonta** (Chr.) H.-Harr. Loch Skiport, S. Uist, Eriskay.
   (3) f. **adenophora** (Gren.) H.-Harr. Near Eaval, N. Uist.

(c) Var. **orbicans** Almq. On sheltered cliffs on the south side of East Loch Tarbert, Harris and on inland cliffs Borve, Barra.

Subcaninae group.

(d) Var. **denticulata** (R. Kell.) H.-Harr. On coast, north of Brevig, Barra; on Heishival, Vatersay.

(We have a very strange form from the north shores of Loch Boisdale, very near var. **Bartlettiana** H.-Harr., which awaits further study and comparisons).

R. mollis Sm. Agg.

(a) Var. **typica** W.-Dod. Quite rare; Ledaig, Barra and Vatersay.

(b) Var. **glandulosa** W.-Dod. Cliffs Nisabost Point, S. Harris and along a stream west of Dun Clach, Taransay.

R. Sherardi Dav. Agg.

(a) Var. **typica** W.-Dod. Scattered down the east coast of S. Uist.
   (1) f. **submollis** Ley. Hacklate and cliffs near the pier Gt. Bernera: Kyles Stuley on the east coast of South Uist; Rueval etc., Benbecula; Eriskay, Fuday; Borve, Ledaig, Allt Heiker etc., Barra and Sandray.
   (2) f. **pseudomollis** Ley. Thinly scattered on Harris, North Uist, Benbecula, South Uist, Barra and Sandray.
   (3) f. **uncinata** Lees. A form near this was collected on the cliffs, Tobson, Gt. Bernera.

(b) Var. **omissa** (Déségl.) H.-Harr. Sparsely in the south of N. Uist and down the east of S. Uist.
   (1) f. **resinosoides** (Crèp.) H.-Harr. Kyles Stuley, S. Uist.

(c) Var. **suberecta** (Ley.) H.-Harr. Cliffs at Earshader, near Hacklate, Gt. Bernera; Corodale, S. Uist; north Craigastrome, Benbecula; the east coast of Barra and cliffs an Sandray.

(d) Var. **Cookei** H.-Harr. Cliffs of the Croir area, Gt. Bernera; base of Eaval, S. Uist; along the shores of Loch Boisdale etc., S. Uist, and Brevig, Barra.

R. spinosissima L.

As var. **typica** W.-Dod on a cliff ledge near Tangusdale, Barra.

Sorbus Aucuparia L. Mountain Ash.
On rocks, cliffs and islands in lochs and often quite common; Lewis, Harris, Taransay, Great and Little Bernera, N. Uist, Benbecula, S. Uist, Eriskay and Barra.

***Cratægus Oxyacantha** L. Hawthorn.
Two or three trees on the cliffs on the north side of Loch Boisdale; almost certainly native.

SAXIFRAGACEÆ.

***Saxifraga oppositifolia** L. Purple Saxifrage.
Gullies and cliffs Cnoc Eadar da Bheinn, N. Harris; cliffs in Corodale and on Hecla, S. Uist.

***S. stellaris** L. Starry Saxifrage.
Plentiful in moist places on Cnoc Eadar dà Bheinn, N. Harris, Uamasclett, S. Harris and in the Bheinn Mhor, Hecla mountains S. Uist.

***S. tridactylites** L.
Common on the machair, Baleshare, in early spring; no doubt it occurs in similar places elsewhere.

***Chrysosplenium oppositifolium** L. Opposite-leaved Golden Saxifrage.
Gorge of the Abhainn Gheatry and also on shady rocks to the south of Loch Eynort, S. Uist; very rare in both stations.

CRASSULACEÆ.

***Tillaea muscosa** L. Mossy Tillaea.
Exceedingly local on almost pure sand in the south-west corner of Barra. The form appears to be perennial, as a plant collected in August 1939 is now (Dec. 1940) still alive.

Sedum roseum Scop. Roseroot.
Frequent on mountains and sea cliffs; Glen Valtos (L.), G.B., L.B., T., Cnoc Eadar da Bheinn (N.H.), Uamasclett and Toe Head (S.H.), Eaval (N.U.), P.H., Beinn Mhor (S.U.), E., B., V., S., Mul., P.B., M., and B.B.

S. anglicum Huds. English Stonecrop.
Abundant in rocky places in almost every island from Lewis to Barra Head.

S. acre L. Biting Stonecrop.
Common on sandy ground near the sea except on G.B., Fy., Mul., M., and B.B.

DROSERACEÆ.

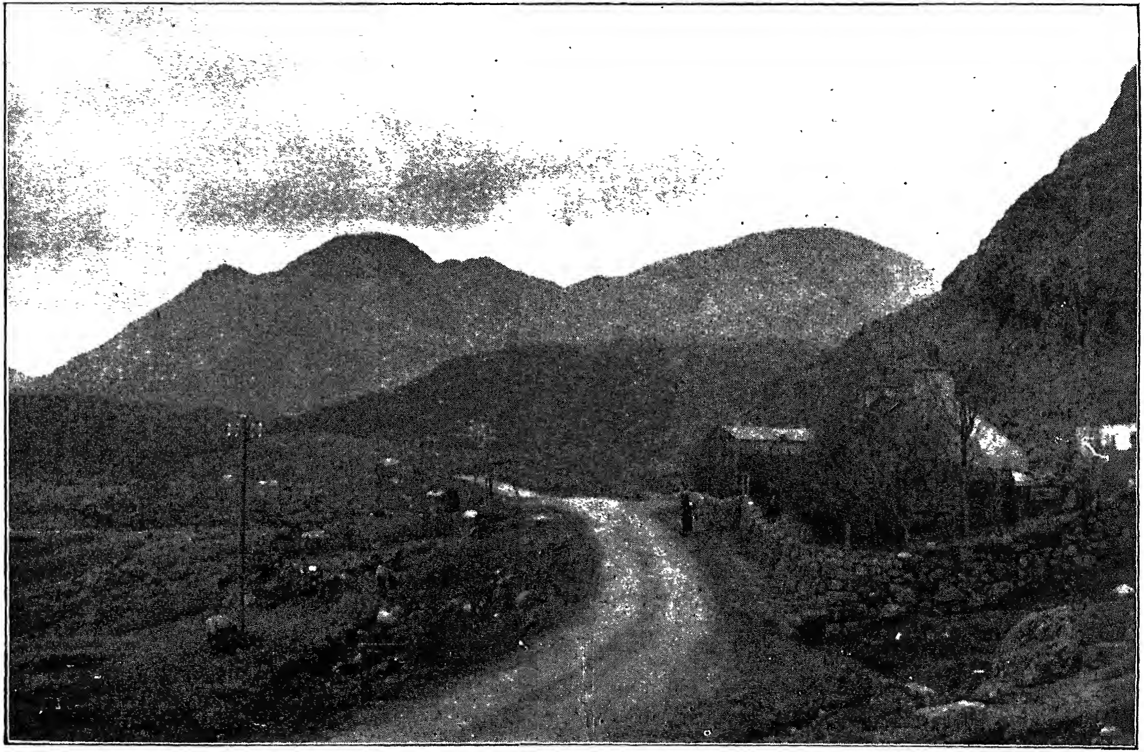
Drosera rotundifolia L. Round-leaved Sundew.
Common in bogs on every island except the smallest ones.

D. anglica Huds. Long-leaved Sundew.
Of common occurrence in bogs and on loch margins; Uig area (L.), G.B., T., H., N.U., Ben., S.U., and Barra.

***D. longifolia** L. Lesser Long-leaved Sundew.
Abundant in similar stations to the last on the moorlands of S. Uist; more local on Eriskay and Barra.

HALORAGACEÆ.

***Hippuris vulgaris** L. Mare's-tail.
Not uncommon around lochs and slow streams in the machair areas of North Uist, Monach Isles, Baleshare, Berneray (H.), Benbecula, S. Uist, Eriskay and Fiaray; only near Caolis, Vatersay.



(*Photo. by W. A. Clark*).

Fig. 3. Clisham and the cliffs of Cnoc Eadar dà Bheinn: N. Harris.

Myriophyllum spicatum L. Water Milfoil.
Local, but where found not rare; Little Loch Borve, Berneray (H.), shallow lochs on Benbecula, S. Uist and Barra.

M. alterniflorum DC.
Of freer occurrence than the last; Loch Sgailler, Valtos, Ard Uig (L.), Loch Tana (G.B.), Loch Sniogravat (Mo.), Pabbay (H). Berneray (H.), and thence on all the larger islands from Benbecula southward to Sandray.

Callitriche stagnalis Scop. Water Starwort.
Common on all the more important islands.

C. intermedia Hoffm.
Not so plentiful as the last; only recorded from Monach Isles, Taransay, Uig District, Lewis, Benbecula, S. Uist, Barra and Vatersay.

***C. autumnalis** L.
Rather rare; Loch na Liana Moire etc., Benbecula; Loch Ollay, Loch Altabrug, S. Uist.

LYTHRACEÆ.

***Peplis Portula** L. Water Purslane.
Occasional in ditches etc., by path sides on Benbecula and S. Uist.

***Lythrum Salicaria** L. Purple Loosestrife
Sparingly on the margin of Loch Ardvule, S. Uist.

ONAGRACEÆ.

***Epilobium angustifolium** L. Rosebay Willow-herb.
On rock ledges; north slope of Eaval, N. Uist, near Sythe Harbour, Taransay, south shore of Loch Eynort and Glen Corodale, S. Uist. Differs from the now widely spread common form, and roots were removed in 1939 from S. Uist for study.

E. parviflorum Schreb. Downy Willow-herb.
Not uncommon in marshes etc., on most of the islands, even the Monachs.

E. montanum L. Smooth-leaved Willow-herb.
Occasionally in shady places and cliff ledges from Tarbert, Harris to Barra.

***E. tetragonum** Curt.
Not common from Eriskay to the Ormaclett district of S. Uist.

***E. Lamyi** F. Schultz.
This species, of which we formerly confused Fuday specimens with the related *E. tetragonum*, was entirely unexpected in the Outer Hebrides. None the less. we possess examples collected on Fuday, Eriskay and in the south-central districts of S. Uist.

E. obscurum Schreb.
Frequent on most islands from Little Bernera (Lewis) to Barra; examples from Berneray (H.) are very fine.

***E. adenocaulon** Huds.
A recent immigrant now well distributed in southern England, reported here from the Bornish-Stoneybridge area, S. Uist — also from Coll. It is an American species and may not be a colonist in the Hebrides.

E. palustre L. Marsh Willow-herb.
Very abundant in wet places from Lewis to Berneray (B.).

E. palustre × **E. parviflorum.**
A hybrid found on Taransay.
***E. alsinefolium** Vill.
Exceedingly rare; only on Sheaval, S. Uist.

UMBELLIFERAE.

Hydrocotyle vulgaris L. Marsh Pennywort.
Universally common in wet places.
***Eryngium maritimum** L. Sea Holly.
Local and often rare; opposite Kirkibost Island. N. Uist; Daliburgh, S. Uist; dunes in the west of Barra; Pabbay (B.) and Mingulay.
Conium maculatum L. Hemlock.
Occasionally in waste places near houses; Pabbay (H.), Berneray (H.), Eriskay and Barra.
Apium nodiflorum Reich. fil.
Often abundant in ditches etc.; from Taransay and Pabbay (H.) southward to Barra.
Apium inundatum Reichb.
Also common enough in almost all the islands from Lewis to Barra.
***Cicuta virosa** L. Cowbane.
Rather common in Loch na Liana Moire and the adjacent drainage lodes, but rare in Loch Eilean an Staoir, South Uist.
***Carum verticillatum** Koch. Whorled Caraway.
Very rare; on damp grassy slopes near Loch Eynort, S. Uist.
***Sium erectum** Huds. Water Parsnip.
Plentiful in one stream near Heisinish, Eriskay.
Aegopodium Podagraria L. Goutweed.
As a weed; Uig, Lewis; N. Uist, Harris, Benbecula and near Castlebay, Barra.
Chærophyllum temulum L. Rough Chervil.
Not common on sandy ground, Benbecula and S. Uist.
Anthriscus sylvestris Hoffm. Wild Beaked Parsley.
Rather rare and local; S. Uist, Barra, Vatersay, Pabbay (B.) and Mingulay.
***Oenanthe Lachenalii** C.Gmel. Parsley Water Dropwort.
Wet places near the sea; near Loch Sniogravat, Ceann Ear, Monach Isles; behind An Tom, Benbecula; Loch Eynort etc., S. Uist.
***Oe. crocata** L. Water Dropwort.
Occasional near the sea, Harris; Lochmaddy, N. Uist; Loch Eynort, Lochboisdale, S. Uist; Eriskay and Ersary, Barra.
Ligusticum scoticum L. Lovage.
Not uncommon on precipitous cliffs, and sometimes on sand dunes and shingle; on every island from Lewis to Barra Head save N. Uist, Flodday and Fuday; overlooked, in all probability, on N. Uist and Flodday.
Angelica sylvestris L. Cow Parsnip.
Generally very common on every island except the Monach group.
Heracleum Sphondylium L. Cow Parsnip.
Less plentiful than the preceding, and lacking on Pabbay (H.), Fiaray, Muldoanich and Flodday.
Daucus Carota L. Wild Carrot.
Locally abundant on sandy ground on every island from Lewis to Berneray (B.) except Fiaray, Muldoanich, Flodday and Sandray.

Caucalis Anthriscus Huds. Upright Hedge Parsley.
In sandy cultivated ground on Taransay, Eriskay, Barra and Vatersay.

ARALIACEÆ.

***Hedera Helix** L. Ivy.
Generally rare on inland cliffs, but sometimes well grown bushes grow on the coast, as in Glen Corodale, S. Uist. Other localities are near the Ferry pier, Great Bernera, Glen Valtos (L.), East Loch Tarbert (H.), Taransay, cliffs south of Maari, N. Uist, Allt Volagir (S.U.), where it forms magnificent clumps on the rocks of the gorge, Allt Heiker and elsewhere (B.) and Mingulay Bay (M.).

CAPRIFOLIACEÆ.

Sambucus nigra L. Elder.
Occasional old bushes growing in widely separated points on Benbecula. S. Uist, and Barra have been, no doubt, planted or are escapes.

***Lonicera Periclymenum** L. Honeysuckle.
Occurs commonly on rocks on the larger islands from Harris to Mingulay as well as on Taransay. Var. *Clarki* H. Harrison, a very striking form, with broad glabrous subcoriaceous leaves, was discovered on many islands from Great and Little Bernera and Lewis to Pabbay (B.). Var. *quercifolia* Aiton, with lobed sinuate leaves, turned up on a rock ledge on Rueval, Benbecula.

RUBIACEÆ.

Galium verum L. Yellow Bedstraw.
Common on the machair on every island except Fiaray, Muldoanich and Flodday; also var. *maritimum* DC. on South Uist.

G. saxatile L. Heath Bedstraw.
Occasionally not rare on rocky moorlands on most of the more important islands, but very rare on Fuday and Sandray.

G. palustre L. Marsh Bedstraw.
Frequent in moist places, but seemingly absent from Sandray, Pabbay (B.), Flodday and Muldoanich.

G. uliginosum L. Bog Bedstraw.
Very rare, Kildonan, S. Uist, and Vatersay.

G. Aparine L. Cleavers.
This plant, with its var. *minima*, occurs as a weed or a shingle plant on every island worked except Flodday and Muldoanich.

***Sherardia arvensis** L. Field Madder.
Rare, on the "machair," S. Uist.

VALERIANACEÆ.

Valerianella olitoria (L.) Poll. Lamb's Lettuce.
Sometimes not rare on sandy ground; Luskentyre (S.H.), N.U., L.B., P.H., S.U., E., B., V., and S.

***Valeriana officinalis** L. Greater Valerian.
Generally on cliffs near the sea; locally not rare on the east coast of S. Uist, also inland along a stream near Howmore in the same island; likewise near Ersary, Barra.

DIPSACEÆ.

Succisa pratensis Mœnch. Devil's Bit Scabious.
Very abundant on every island except Baleshare and the Monachs; on Flodday it barely attains a height of three inches.

***Knautia arvensis** (L.) Coult. Field Scabious.
A few well grown plants in the same habitat as the Ononis on Vatersay, also rarely at a second point east of this.

COMPOSITAE.

Solidago Virgaurea L. Golden Rod.
Common and widely distributed in rocky places from Lewis to Mingulay; no specimens, however, were collected on Mo., B.H., P.H.. Bal., F., and Fl. Mountain forms on S. Uist should probably be referred to var. *cambrica* Huds.

Bellis perennis L. Daisy.
Very common everywhere except Flodday.

Aster Tripolium L. Sea Aster.
Sometimes abundant in salt marshes; Caranish, N. Uist; Loch Borve, Bernerav (H.); Benbecula and S. Uist.

Antennaria dioica Gærtn. Mountain Everlasting.
Common in rocky, heathy stations and often at sea level; not on Bal., Mo., Fl. and Fy.

Gnaphalium uliginosum L. Marsh Cudweed.
Locally common; Benbecula, S. Uist, Eriskay and Barra.

***G. sylvaticum** L. Heath Cudweed.
Only seen in one place near Lochboisdale, S. Uist.

***Inula Helenium** L. Elecampane.
Well established near buildings, deserted crofts, etc.; Paible and Clach an Teampnill, Taransay; Creagorry; Benbecula; Stoneybridge, S. Uist and on Barra.

Achillea Millefolium L. Yarrow.
Common in grassy places, with var. *villosa* Hartm. in S. Uist and doubtless elsewhere.

A. Ptarmica L. Sneezewort.
Scattered on damp moorland in N. Uist, Harris, Taransay, Benbecula, S. Uist, Eriskay, Barra and Vatersay.

Anthemis Cotula L. Stinking Mayweed.
A weed of cultivation; N. Uist, Monach Isles, and near Daliburgh, S. Uist.

Chrysanthemum segetum L. Corn Marigold.
Only amongst corn on the inhabited islands and there too abundant.

C. Leucanthemum L. Ox-eye Daisy.
Rather rare in grassy places on dune and machair; S. Uist, Eriskay and Vatersay.

M. inodora L. Scentless Mayweed.
Often plentiful on cultivated ground from N. Uist and the Monach Isles to Barra. The var. *salina* DC. abounds on coasts from Lewis to Pabbay (B.).

M. matricarioides (Less.) Porter. Rayless Mayweed.
Prevalent occasionally along path sides on all the inhabited islands except Eriskay.

Tanacetum vulgare L. Tansy.
Only near buildings, Uig, Valtos, Callanish, Lewis; Gt. Bernera; N. Uist; Benbecula; S. Uist and Barra.

Artemisia vulgaris L. Mugwort.
Often in similar situations to the last; also on the coast from Lewis to Pabbay (B.) and Sandray.

Tussilago Farfara L. Coltsfoot.
Very local; Barra and Pabbay (B.); also on dunes, Luskentyre and Pabbay, Harris.

Petasites ovatus Hill. Butterbur.
Sometimes common in wet places near the sea; Valtos and Aird Uig (L.), L.B., P.H., B.H., S.U., E., B., V., S., and P.B.

Senecio vulgaris L. Groundsel.
Common on the cultivated islands and also on Pabbay (B.) and Mingulay.

S. Jacobæa L. Ragwort.
Abundant on the machair everywhere, and occassionally on cliff ledges as along the Allt Volagir, S. Uist; not, however, reported from Muldoanich, Flodday and Berneray (B.). The vars. *discoideus* L. and *erucoides* DC. were found on S. Uist.

S. aquaticus Hill. Marsh Ragwort.
In wet places; on the whole generally distributed, but apparently thinning out northward.

S. aquaticus × **S. Jacobæa.**
Often where the parent species clash on Benbecula, S. Uist and Vatersay.

***Arctium nemorosum** Lej. Burdock.
Occasional on sandy ground from Little Berneray and Lewis to Pabbay (B.).

***A. minus** Bernh.
In similar ground to the last near the Standing Stone, Bornish, S. Uist.

Cirsium lanceolatum (L.) Scop. Spear Thistle.
Common enough generally.

C. palustre (L.) Scop. Marsh Thistle.
Very local, although common in restricted areas; Harris, N Uist, Benbecula, S. Uist and Barra.

C. arvense (L.) Scop. Creeping Thistle.
Common usually, but absent apparently from the Monach Isles, Fiaray, Flodday and Muldoanich. The var. *mite* Koch occurs freely in the central machair areas of S. Uist and on Fuday, and var. *integrifolium* on Sandray and Vatersay.

Saussurea alpina DC. Alpine Saw-wort.
Rare on alpine rock ledges; Beinn Mhor and Hecla, S. Uist and Cnoc Eadar da Bheinn, N. Harris.

Centaurea nigra L. (agg.). Knapweed.
Frequent on well drained ground, but missing on the rocky islets. Of its segregates the following were localised:

C. obscura Jord.
Benbecula, S. Uist, Barra and Vatersay.

C. nemoralis Jord.
Lewis, B.H., P.H., N.U., Ben., S.U., E., F., and P.B. The var. *radiata* C. E. Britton was observed on S. Uist and Barra.

***Lapsana communis** L. Nipplewort.
Rare; north end of Barra.

Crepis capillaris Wallr. Common Hawkbeard.
Dry stone dyke Uig, also Callanish, Lewis; locally common on sandy ground from Benbecula to Pabbay (B.). Var. *glandulosa* Druce was detected on S. Uist, but, almost certainly it is to be found elsewhere.

Hieracium anglicum Fr.
As var. *acutifolium* Backh. in Corodale, S. Uist.

H. iricum Fr.
Cliffs, Little Bernera; Skeaudale River, N. Harris; Nisabost Pt., S. Harris.
H. flocculosum Backh.
As var. *longibracteatum* F. J. Hanb. on Hecla, S. Uist.
H. caledonicum F. J. Hanb.
Corodale, S. Uist; Gillaval Glas, banks of Skeaudale River, N. Harris; Vatersay.
H. rubicundiforme Zahn.
In the Black Corrie, Beinn Mhor, S. Uist.
H. Boswelli Linton.
Feavallach, S. Uist.
H. scoticum F. J. Hanb.
Valasay, Gt. Bernera; Beinn Mhor, S. Uist; Heaval and gully behind Loch St. Clair, Barra; Fuday, Muldoanich, Vatersay, Sandray and Pabbay (B.)
H. Schmidtii Tausch.
Rueval, Benbecula, with the var. *crinigerum* F. J. Hanb. on Fuday.
H. Jovimontis Zahn.
Coire Dubh, S. Uist, and in a ravine in the S.W. of Barra.
H. clovense Linton.
Rock ledges on the lower cliffs, north face, Eaval, North Uist.
H. argenteum Fr.
Cliffs near the Pier, Gt. Bernera.
H. nitidum Backh.
On the Isle of Taransay.
H. vulgatum Fr.
On cliffs on Rueval, Benbecula.
H. euprepes F. J. Hanb.
The var. *glabratum* Linton occurred on Beinn Mhor, S. Uist and on Fuday.
H. duriceps F. J. Hanb.
The var. *cravoniense* F. J. Hanb. occurred on the mountain massif, S. Uist.
H. orarium Lindeb.
In the gorge of the Abhainn Gheatry, S. Uist.
H. auratum Fr.
On Fuday only.
H. strictum Fr.
On the mountains, S. Uist.
H. Pilosella L. Mouse-ear Hawkweed.
On every island from Taransay and Pabbay (H.) to Sandray and Pabbay (B.) except Fiaray and Flodday.
H. concinnatum F. J. Hanb.
On low lying, sandy ground on S. Uist, Barra and Vatersay.
Hypochæris radicata L. Cat's Ear.
Quite common from Lewis to Vatersay.
***Leontodon taraxacoides** Lacaita.
Rare on South Uist, Eriskay and Fuday.
L. hispidum L. Hawk-bit.
Rare on dry banks, S. Uist, Eriskay and Fuday.
L. autumnale L. Autumn Hawk-bit.
Common for the most part on the whole of the "Long" Island with var. *pratense* Koch on the machair, S. Uist, and the var. *sordidum* Bab. as common as the type.
Taraxacum vulgare Schrank. Dandelion.
Common from Lewis to Pabbay (B.).

T. lævigatum DC.
Frequent on the machair from Lewis to Sandray and Pabbay (B.).

T. palustre (Lyons) DC.
Wet places, S. Uist.

T. spectabile Dahlst.
Only identified from Vatersay and Flodday, but certainly occurring in other stations.

Sonchus oleraceus L. Sow-thistle.
Cultivated ground and sea cliffs on nearly every island from Lewis to Mingulay.

S. asper Hill. Rough Sow-thistle.
As common as the last; not on Fiaray and Flodday.

S. arvensis L. Corn Sow-thistle.
Rarer northward on Lewis and Harris, but becoming increasingly noxious as a weed in fields in the southern isles; also found on shingle. Clearly increasing since, common as it is, it is regarded as a newcomer on Benbecula.

CAMPANULACEÆ.

Lobelia Dortmanna L. Water Lobelia.
Abundant in many of the lochs; Uig and Gt. Bernera (L.), N.U., T., H., P.H., B.B., Ben., S.U., and B.

Campanula rotundifolia L.
Of common occurrence on dune and machair from Lewis to Pabbay (B.); not recorded from G.B., L.B., Bal., P.H., Fy., Fl., Mul., P.B., B.B. The var. *speciosa* More seems common in the more southern parts of S. Uist, Fuday and Vatersay whilst var. *hirta* M. & K. appears generally common in the Outer Isles.

VACCINIACEÆ.

***Vaccinium Vitis-idæa** L. Cowberry.
Clisham, N. Harris and Hecla, S. Uist; quite rare.

V. Myrtillus L. Bilberry.
Common in some places, but absent from most of the smaller islands; found on Lewis (Glen Valtos), Harris, Taransay, Pabbay (H.), N. Uist, Benbecula, S. Uist, Eriskay (very rare) and Barra.

ERICACEÆ.

Arctostaphylos Uva-ursi Spreng. Bearberry.
Sunny rocks and ledges; Glen Valtos, Lewis; Gt. Bernera; Benbecula, (rare); much more plentiful in the east of South Uist.

Calluna vulgaris (L.) Hull. Heather.
Always abundant on moorlands on all the islands except Mingulay and Berneray (B.) where it is rare. In S. Uist "white heather" appears common.

Erica Tetralix L. Cross-leaved Heath.
Plentiful in wet peaty places; lacking on the islets. White flowered forms are also common on S. Uist.

E. cinerea L. Fine-leaved Heath.
Abundant on rocky banks, moorlands etc., from Lewis to Mingulay, but not on Fiaray, Berneray (H.), Baleshare and the Monachs. Flower colour richer than on the mainland, with white flowered examples more or less prevalent.

PLUMBAGINACEÆ.

Armeria maritima Willd. Sea Pink, Thrift.
Abundant on every island (except Flodday) on rocks and in saltmarshes.

***A. pubescens** Link var. **planifolia** Syme.
A nearly related plant found in some quantity high on the S. Uist mountains.

PRIMULACEÆ.

Primula vulgaris Huds. Primrose.
Very common on every island except Baleshare.

Lysimachia nemorum L. Yellow Pimpernel.
Locally of free occurrence; on cliffs East Loch Tarbert, Harris (rare); in similar places on the east of S. Uist; Barra and, curiously enough, Muldoanich.

Glaux maritima L. Sea Milkwort.
A common coastal plant from Lewis to Mingulay; on the latter island on the top of the highest cliffs.

Anagallis arvensis L. Scarlet Pimpernel.
Usually in cultivated areas in Barra and Vatersay, but on dunes in the east of Fuday.

A. tenella Murr. Bog Pimpernel.
Very plentiful on every island, ascending to 700 feet on Mingulay.

***Centunculus minimus** L. Chaffweed.
Here and there, often where water has stood during the winter and on loch shores; Taransay, Benbecula, S. Uist, Eriskay, Barra, Vatersay and Sandray.

***Samolus Valerandi** L. Brookweed.
Rather rare, on damp ground near lochs; Baleshare, Monach Isles, Loch Bhruist (B.H.), west side of Benbecula, Loch Ollay, Loch Ardvule etc., S. Uist.

OLEACEÆ.

Fraxinus excelsior L. Ash.
Occasionally where planted on S. Uist and Barra.

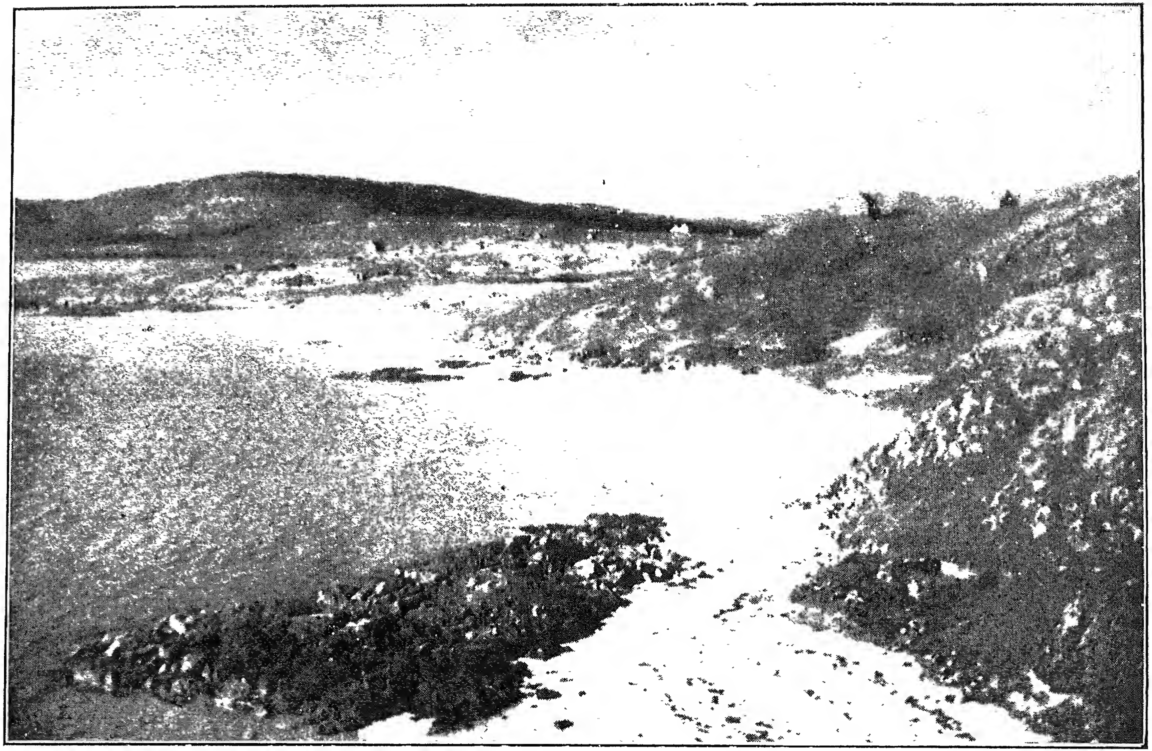
GENTIANACEÆ.

***Cicendia pusilla** Griseb.
We first discovered this species in 1936 in a very restricted area on Raasay where it turned up once again in 1937. Now we can report it from Fuday, where one very poor specimen was collected in 1939, and from the sandy shore of a loch in S. Uist, where a fine specimen was obtained the same season. These occurrences not only extend its range from v.-c. 104 to v.-c. 110, but, in addition, demonstrate that the plant is a true native of the Western Isles.

Centaurium umbellatum Gilib. Centaury.
Very rare and only found near Tangusdale, Barra; the var. *confertum* Wheldon & C. E. Salmon was frequent on most of the islands except Fiaray and Muldoanich.

***Gentiana septentrionalis** Dr.
Only from sand dunes near Valtos, Lewis.

G. campestris L. Field Gentian.
Common enough from Lewis to Sandray, but not seen on Muldoanich and Baleshare.



(Photo. by J. Heslop Harrison).

Fig. 4. Coilleag a'Phrionnsa (Prince Charlie's Cove) Eriskay, the habitat of *Calystegia Soldanella*.

***G. baltica** Murb.
Two forms answering the description of this species have been collected on Taransay, Benbecula, S. Uist, Eriskay, Barra, Fiaray, Vatersay and Flodday. One of these, in our view, represents weak forms of *G. campestris;* the other, from Taransay, S. Uist and Eriskay, we regard as true *G. baltica.*

Menyanthes trifoliata L. Bogbean.
Common in spongy bogs and lochs, although not seen on the smaller rocky islands.

BORAGINACEÆ.

Lycopsis arvensis L. Small Bugloss.
As a weed of cultivation on all the larger islands, missing from the others except Sandray. At times it occurs on cliffs, as in Corodale, S. Uist, far away from the cultivated areas.

Myosotis cæspitosa Schultz. Forget-me-not.
Frequent in marshy ground upon all the most important islands.

M. repens G. & D. Don.
S. Uist, Lochmaddy (N. Uist), and on the shores of Loch Breaclete, Gt. Bernera.

M. arvensis Hill. Field Scorpion Grass.
Common on cultivated and sandy ground in most of the islands.

M. lutea (Cav.) Pers. Changing Forget-me-not.
In the guise of var. *pallida* Breb. in similar stations to the last, although less frequent on Lewis, Harris, N. Uist, Benbecula, S. Uist, Eriskay, Barra and Mingulay.

***Lithospermum arvense** L. Corn Gromwell.
Very rare, only observed on the dunes and in cultivated areas near Valtos, Lewis.

***Echium vulgare** L. Viper's Bugloss.
On the dunes near Dun Clach and on the machair near Paible, Taransay.

CONVOLVULACEÆ.

***Calystegia sepium** Br. Greater Bindweed.
In a dune hollow near Daliburgh, S. Uist; as an escape and on "garden fences" common on Barra.

***C. Soldanella** Br. Sea Convolvulus.
Sand dunes close to the sea; rare on the west side of Eriskay; locally abundant on Traigh Varlish, Vatersay, where white flowered forms occur with the type.

***Convolvulus arvensis** L. Field Convolvulus.
Rare and local amongst rye near the Village, Vatersay.

SCROPHULARIACEÆ.

***Scrophularia nodosa** L. Figwort.
Exceedingly rare, as a curious dwarf form, quite unlike the usual plant, on cliffs on the south shore of Loch Eynort, S. Uist.

Digitalis purpurea L. Foxglove.
Locally common on rocks, in stream gorges etc. on N. Uist, Harris, Taransay, Benbecula, S. Uist and Barra.

***Veronica persica** Poir. Buxbaum's Speedwell.
Rare in Harris.

V. agrestis L. Field Speedwell.
Rare, in crops, Lewis, S. Uist, Barra, Vatersay.

V. arvensis L.
Not uncommon in similar places at many points from Lewis to Mingulay.

V. serpyllifolia L. Thyme-leaved Speedwell.
Very rare on grassy slopes, Harris, N. Uist and on the north shore of Loch Eynort, S. Uist.

V. officinalis L. Common Speedwell.
Steep slopes and rock ledges; locally not uncommon, on Harris, N. Uist, S. Uist and Barra; rare and very local on cliff ledges on Benbecula, Sandray, Muldoanich and Pabbay. Sometimes, as on Sandray, a single plant would provide the record for the island.

***V. Chamædrys** L. Germander Speedwell.
Very local on a bankside near Castlebay, Barra.

V. scutellata L. Marsh Speedwell.
Lowland marshes, very rare, Hacklate, Gt. Bernera (Lewis) and Stoneybridge, S. Uist; var. *hirsuta* Weber was also gathered.

V. Anagallis-aquatica L. Water Speedwell.
Margins of pools, ditches etc.; sporadically abundant from Lewis to Vatersay; not seen in Harris, Taransay, and the islands south of Vatersay. The var. *anagallidiformis* (Bor.) Krosche was noted on Fuday.

V. Beccabunga L. Brooklime.
Ditches, small streams; marsh near Sollas Aerodrome, N. Uist; Barra; Eorisdale, Vatersay; and Fuday.

Euphrasia micrantha Reich. Eyebright.
Everywhere common on heathy situations from Lewis to Mingulay. Of the varieties, var. *Johnstonii* Pugsley was collected near Ormaclett Castle, S. Uist, Eoligarry, Barra and Fuday, and var. *simplex* on many widely separated stations.

E. micrantha × **E. confusa.**
On Benbecula.

E. micrantha × **E. scotica.**
Muldoanich and Pabbay (B.).

E. micrantha × **E. nemorosa** var. **collina.**
Eoligarry, Barra.

E. micrantha × **E. brevipila.**
Fuday and Taransay.

E. scotica Wettst.
Collected on Fuday, Sandray, Muldoanich and Pabbay (B.), with var. *purpurascens* Pugsl. from Hecla and Beinn Mhor, S. Uist; Muldoanich; and Glen Valtos, Lewis.

***E. frigida** Pugsl.
Only on Hecla, S. Uist.

***E. foulænsis** Towns.
Found on Hecla and Beinn Mhor, S. Uist, Sandray, Muldoanich, Flodday and Pabbay (B.); form *maritima* Pugsl. occurred on Fiaray.

***E. Marshallii** Pugsl.
This remarkable form was discovered both on Muldoanich and Flodday.

E. curta (Fr.) Wittst.
Hacklate, Gt. Bernera with the var. *glabrescens* Wittst. on Little Bernera, Eriskay, Monach Isles, S. Uist, and Sandray.

***E. occidentalis** Wittst.
Flodday specimens are possibly typical, but the var. *minor* was noted on Muldoanich, and the var. *calvescens* Pugsl. more commonly and widely spread on Benbecula, Barra, Fiaray, Flodday, Vatersay, Sandray and Pabbay (B.).

E. nemorosa Löhr var. **collina** Pugsl.
Often very abundant on machair and dunes throughout the "Long Island." The var. *sabulicola* Pugsl. was noted at Eoligarry, Barra.

E. confusa Pugsl.
Occasionally in short turf, often near the sea; Fuday, Heaval (Barra), Sandray and Muldoanich. The form *albida* Pugsl. seems rather more frequent than the preceding in similar situations on Benbecula; Loch Skiport (S. Uist); Heaval and Eoligarry (Barra); Sandray and Pabbay (B.). The form *grandiflora* Pugsl. was gathered in Glen Valtos (Lewis).

E. confusa × **E. occidentalis.**
Forms, probably representative of this hybrid, were brought from Sandray.

E. brevipila B. and G.
Taransay, Mingulay and Berneray (B.); the form *subeglandulosa* Towns. was noted on Lewis at Uig, S. Uist, Barra and Fuday.

E. brevipila × **E. nemorosa** var. **collina.**
Loch St. Clair, Barra; Loch Ollay, S. Uist.

E. Campbellæ Pugsl.
Breaclete, Gt. Bernera.

Bartsia Odontites Huds. Red Bartsia.
Frequent and on all the islands except Baleshare, Muldoanich and Flodday.

Pedicularis palustris L. Marsh Lousewort.
Common in wet peaty places; not on Mingulay and Flodday.

P. sylvatica L. Lousewort.
Abundant in similar places; lacking on the Monach Isles, Fiaray and Flodday.

***Rhinanthus minor** Ehr. Yellow Rattle.
Near Uachdar, Benbecula; Kildonan to Bornish, S. Uist; Pabbay and Tarbett, Harris, with the var. *pubescens* near Daliburgh, S. Uist; never common.

***R. major** Ehr. Yellow Rattle.
Rare on land lying fallow on Vatersay.

R. stenophyllus Schur.
The common Yellow Rattle of the islands from Lewis to Pabbay (B.); not seen on the smaller uninhabited ones except Fuday and Pabbay (B.). A form of this, with yellow flowers and no black stripes on the stems, was noticed near Loch Ollay, S. Uist.

***R. monticola** (Stern.) Dr.
Little Bernera, Monach Isles and Pabbay (H.), and Benbecula.

***R. Drummond-Hayi** (Stern.) Dr.
Rare; only on the Beinn Mhor, Feaveallach, Hecla group of mountains, S. Uist.

***R. spadiceus** Wilm.
Found, with forms near the var. *orcadensis* Wilm. on the Isle of Berneray (H.).

OROBANCHACEÆ.

***Orobanche rubra** Sm. Broom-rape.
Very rare near Pollachar and in Glen Corodale, S. Uist; rare in Eriskay, but abundant and very fine in Fuday.

LENTIBULARIACEÆ.

Utricularia vulgaris L. Bladderwort.
U. neglecta Lehm.
As no plants were found in flower, these two could not be separated with certainty, although we are of the opinion that most of the plants were *U. vulgaris*. Rare in a loch behind Post Office, Berneray (H.), common in S. Uist, less so on Eriskay and Barra.
U. minor L.
Quite common in lochs, streams etc., on Gt. Bernera, Pabbay (H.), Berneray (H.), S. Uist, Barra, Vatersay, Sandray and Pabbay (B.).
U. intermedia Hayne.
Also of common occurrence; Glen Valtos (Lewis), Gt. Bernera, Berneray (H.), Pabbay (H.), S. Uist, Eriskay, Barra and Vatersay,
Pinguicula vulgaris L. Common Butterwort.
Abundant everywhere in suitable wet places; lacking on the Monach Isles and Fiaray.
P. lusitanica L. Pale Butterwort.
As widely spread as the last, but not so common; not seen on Fuday, Fiaray and Flodday.

LABIATAE.

Mentha viridis L. Mint.
No doubt an escape; S. Uist and Barra.
M. aquatica L. Water Mint.
Common in wet places; not collected on Eriskay, Fiaray, Flodday and Muldoanich.
M. arvensis L. Corn Mint.
In the deserted fields on Mingulay.
Lycopus europæus L. Gipsywort.
Occasional in ditches, wet places by the sea, and even on shingle; S. Uist, Eriskay, Barra (where it was locally common) and in a marsh near the Keeper's House, Mingulay.
Thymus Serpyllum L. **(sens. lat.)** Thyme.
Very abundant and one of the common plants on every island. Of its segregates the following six were critically examined :—
T. Serpyllum L.
Well distributed with var. *ericoides* on Taransay and Muldoanich.
T. pycnotrichus Ronn.
S. Uist, Barra, Fuday, Vatersay and Sandray.
T. Drucei Ronn.
S. Uist, Flodday and Pabbay (B.).
T. zetlandicus Ronn. and Dr.
Benbecula, Fiaray and Sandray.
T. neglectus Ronn.
Uig, (L.), Tarbert (H.), Taransay, Bayhead (N.U.), S. Uist, Barra, Fiaray, Vatersay and Pabbay (B.).

T. britannicus Ronn.
Little Bernera, S. Uist, Barra, Fiaray, Fuday, Vatersay and Sandray.

T. ovatus Mill.
Very rare and far from universal even on islands where it does occur; S. Uist, Barra, Fuday, Flodday and Muldoanich.

***Scutellaria galericulata** L. Greater Skull-cap.
Rare, and of limited distribution, on shingle; East Loch Tarbert, Harris; Loch Skealtar, N. Uist; Loch Eynort, S. Uist.

***S. minor** Huds. Lesser Skull-cap.
Locally common and often in sphagnum bogs; Loch Baravat (Gt. Bernera), Glen Valtos (L.), Ben Lee (N.U.), Taransay; Rueval and several other places from Craigastrome northward to Loch Dubh (Benbecula); S. Uist, Barra, Eriskay, Vatersay (quite rare) and Sandray.

Prunella vulgaris L. Selfheal.
Very plentiful and on every island, sometimes with very large flowers; the Flodday population is composed of exceedingly tiny specimens.

***Stachys palustris** L. Marsh Woundwort.
At isolated points; Callanish, Lewis; Lochmaddy, N. Uist; Berneray (H.), and in the east of Barra.

*× **S. ambigua** Sm. = **S. palustris** × **S. sylvatica.**
Castlebay, Barra.

***S. sylvatica** L. Hedge Woundwort.
Locally in some plenty in a restricted area north of Lochboisdale.

S. arvensis L. Field Woundwort.
Rare in corn crops etc., S. Uist and Barra.

Galeopsis Tetrahit L. Common Hemp Nettle.
A frequent weed of cultivation; Benbecula, S. Uist, Eriskay, Barra and Vatersay.

Lamium amplexicaule L. Hen-bit.
Uig (Lewis); Taransay, Toe Head (Harris); Eriskay; Castlebay etc. (Barra) and Vatersay.

***L. molucellifolium** Fr.
Valtos (Lewis), Taransay, Benbecula, S. Uist, Eriskay, Barra and Mingulay; irregularly distributed as a weed or relic of cultivation.

L. hybridum Vill.
At similar points to the last on S. Uist, Barra and Vatersay.

L. purpureum L. Red Deadnettle.
Commoner than the preceding species from Lewis to Vatersay, in worked ground.

Teucrium Scorodonia L. Wood Sage.
Inland on rocky ground and cliffs, and sometimes common; Glen Valtos (Lewis); banks of Skeaudale River (N.H.); Gt. Bernera; Loch Eynort, Loch Skiport, Loch Boisdale (S.U.); Allt Heiker (Barra).

Ajuga reptans L. Bugle.
Plentiful in the Beinn Ruigh Chinnich area, S. Uist; very rare indeed, in a narrow ravine in the south east of Sandray.

***A. pyramidalis** L. Pyramid Bugle.
Occasionally common on steep slopes to the north of Loch Boisdale and along Allt Volagir, S. Uist; rare in two or three stations in the Heaval and Ben Olosay areas and also near Loch Obe, Barra and not common on Muldoanich. The two species overlap on Loch Boisdale but no hybrids were noted.

PLANTAGINACEÆ.

Plantago Coronopus L. Stag's Horn Plantain.
Everywhere abundant in rocky places etc., near the sea and sometimes far inland.

P. maritima L. Sea Plantain.
Just as frequent as the last and also common on inland cliffs where it is variable.

P. lanceolata L. Ribwort Plantain.
Abundant everywhere.

P. major L. Greater Plantain.
Common on pathsides, but not seen on the abandoned islands.

Littorella uniflora Aschers. Shoreweed.
In quantity in and around lochs and pools; on all the islands except L.B., Bal., Mo., F., Fy. and F.

ILLECEBRACEÆ.

***Illecebrum verticillatum** L.
Very rare in a limited sandy and gravelly area in S.W. Barra. As this plant, according to the Floras, was only known for the South of England, this was a very unexpected find. However, Goodrich-Freer reported it in 1903 from Eriskay — a record previously overlooked.

***Herniaria ciliata** Bab.
This surprising find, when taken, was passed over as some obscure form of Polygonum and reserved for study at home; hence it is not known to what extent it occurs on sandy ground in the Daliburgh, Kildonan area of S. Uist where it was discovered. As soon as it was determined to be a Herniaria it was sent to Mr. Pugsley who named it as *Herniaria ciliata* var. *angustifolia* Pugsl., but stated that it was an unusual form and not, therefore, typical. The variety *angustifolia* has only been reported previously from Jersey.

CHENOPODIACEÆ.

Chenopodium album L. Goosefoot.
Here and there on waste and cultivated ground, S. Uist, Eriskay, Barra and Mingulay.

***C. opulifolium** Schrad.
This alien was collected in a field on Vatersay.

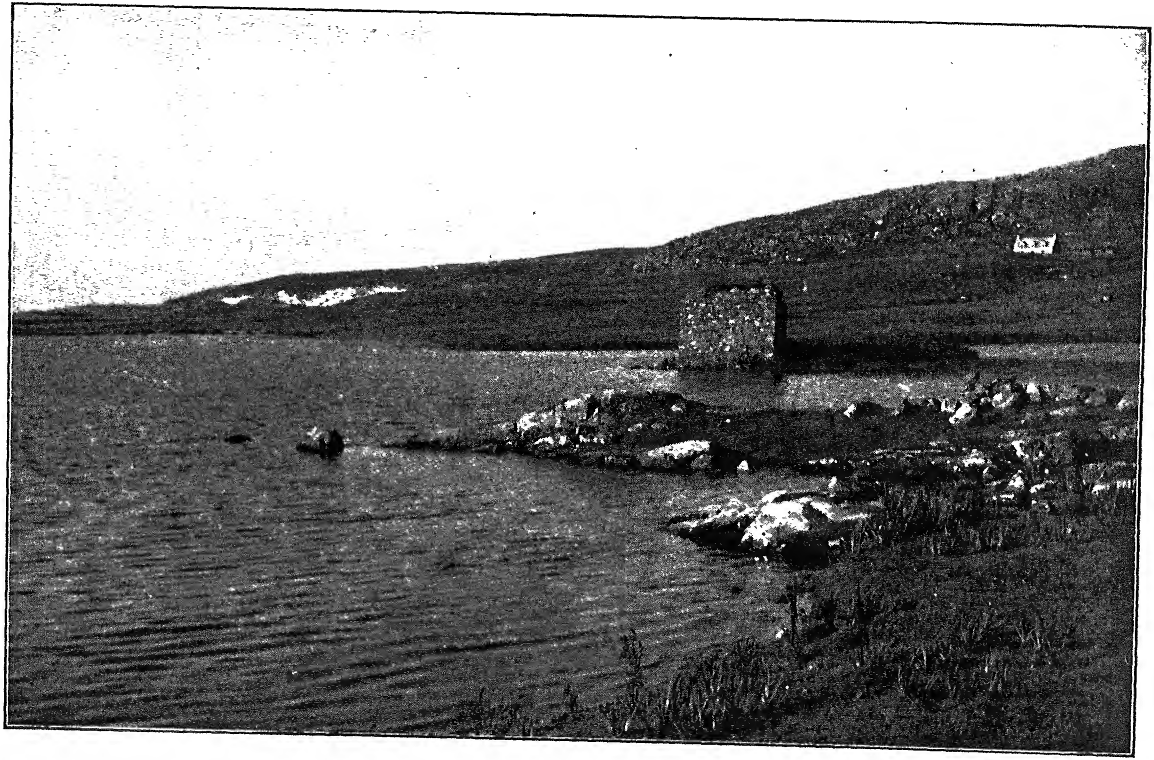
***Atriplex littoralis** Grass-leaved Orache.
Only noted on Bagh Scar, Vatersay and on the adjacent island of Flodday.

***A. patula** L.
This is definitely not common and can only be recorded with certainty from the sea shore near Borve, Benbecula.

A. hastata L.
In waste places etc., not common on S. Uist, Eriskay and Barra.

A. laciniata L.
We have records of this from the coasts of every island visited except Barra, chiefly from the western shores of the more northerly islands, but more generally southward.

A. glabriuscula Edmondston.
On the west sides of Benbecula, South Uist and Barra.



(*Photo by W. A. Clark*).

Fig. 5. Loch St. Clair, Barra, the area favoured by many southern plants.

Salicornia stricta Dum.
Gt. Bernera; North Ford, South Ford, Creagorry, Benbecula; Loch Eynort, Lochboisdale, S. Uist and Barra.

***S. gracillima** (Towns.) Moss.
N. Uist; near Uachdar, Benbecula; Loch Skiport, Loch Eynort, S. Uist; Barra.

***S. ramosissima** Woods.
Near Uachdar, on mud flats, Benbecula and near Carnan, S. Uist.

***S. prostrata** Pallas.
Rare under the sea wall toward An Tom in N. Benbecula.

Suæda maritima Dum. Sea Blite.
In salt marshes and on muddy sea shores; Loch Borve, Berneray (H.); Carinish, N. Uist; North Ford (Uachdar etc.), Benbecula; South Ford, Loch Eynort, S. Uist.

Salsola Kali L. Saltwort.
Rare, sandy sea shore, Eriskay and Pabbay (B.).

POLYGONACEÆ.

Polygonum Convolvulus L. Bindweed.
Not common, cultivated ground, Berneray (H.), Benbecula, S. Uist, Eriskay and Barra.

P. aviculare L. (agg.) Knotgrass.
As an aggregate this has been noted on cultivated and waste ground on all the major islands from Lewis to Mingulay. Of its segregates we have the following records:—

***P. æquale** Lindman.
Uig, (L.), T., H., Mo., Ben., S.U., E., and Barra.

***P. heterophyllum** Lindman.
South Uist and Barra.

P. Raii Bab.
Not uncommon; Daliburgh, etc., S. Uist, Eriskay, Fuday, Vatersay Bay, Vatersay, and Bagh Ban, Pabbay (B.).

***P. Hydropiper** L. Water Pepper.
Rare near Creagorry, Benbecula and also near Castlebay, Barra.

P. Persicaria L. Spotted Persicaria.
Often a real pest in fields, and occasionally observed near the sea shore, from Lewis to Mingulay.

P. amphibium L. Water Persicaria.
Fairly common in lochs, ditches and as var. *terrestre* on damp ground; L.B., N.H., S.H., T., P.H., Ben., S,U., E., B., V., and S.

P. cuspidatum Sich. & Zucc.
As a garden escape; Stoneybridge, S. Uist and Benbecula.

***P. viviparum** L.
At sea level on machair land on Little Bernera and at Uig, Lewis; as is generally known these records of ours provided the first for Little Bernera and Lewis, respectively.

***Oxyria digyna** Hill. Mountain Sorrel.
On cliffs, Cnoc Eadar Dà Bheinn, N. Harris; mountain cliffs on Bheinn Mhor, Feaveallach and Hecla, and on sea cliffs north of Loch Boisdale, S. Uist; at sea level in a gorge west of Bagh Ban, Pabbay (B.); cliffs on Mingulay.

Rumex obtusifolius L. Broad-leaved Dock.
Frequent, waste places, near the sea and elsewhere.

R. crispus L. Curled Dock.
Common everywhere on rocky places near the shore and on shingle.

R. Acetosa L. Sorrel.
Very plentiful in grassy places on every island.

R. Acetosella L. Sheep's Sorrel.
Locally abundant but missing, or unobserved, in the uninhabited islands.

[**Rumex** sp? What may prove to be *R. arifolius* All. or an endemic form was found on S. Uist, Eriskay, Mingulay and Berneray (B.)].

EUPHORBIACEÆ.

Euphorbia Helioscopia L. Sun Spurge.
Common on all islands with cultivated land, with Mingulay in addition.

URTICACEÆ.

Humulus Lupulus L. Hop.
Common on a fence along the roadside near Glen, in an angle of a field and elsewhere near Castlebay, Barra.

Urtica dioica L. Nettle.
Common, especially about buildings, deserted and otherwise.

U. urens L. Annual Nettle.
Occasionally on waste and cultivated land from Harris to Mingulay.

MYRICACEÆ.

Myrica Gale L. Bog Myrtle.
Common at some points, rare at others; Glen Valtos, (L.), Loch Dun an t-Siamain, N. Uist, (rare), Benbecula, S. Uist, Eriskay and Barra.

CUPULIFERAE.

Betula pendula Roth. Silver Birch.
North of Loch Boisdale and Allt Volagir, S. Uist.

B. pubescens Ehrh. Birch.
Occasionally in sheltered places and sometimes as well-grown trees, Allt Volagir and to the north of Mt. Hecla, S. Uist; around Loch Obe and elsewhere, Barra. Well developed trunks occur in the peat in many places.

Alnus glutinosa Gærtn. Alder.
Tarbert, (Harris); Lochmaddy and Newton, N. Uist; Northbay, Barra, almost certainly planted.

Corylus Avellana L. Hazel.
At widely separated points in sheltered rocky places; Glen Valtos, Lewis; Great and Little Bernera; Glen Skeaudale, N. Harris; N. Uist; Allt Volagir, Loch Eynort, etc., S. Uist; Rueval, lochsides etc., Benbecula; Eriskay; Allt Heiker etc., Barra. In August, in a healthy hazel wood on S. Uist, ripe nuts were quite plentiful; which perhaps has some bearing on the reports of hazel nuts in peat on that island and elsewhere.

SALICACEÆ.

Salix pentandra L. Bay-leaved Willow.
In the north of Barra; planted.

S. fragilis L. Crack Willow.
Planted occasionally on Benbecula and S. Uist.

***S. alba** L. White Willow.
On an island in a loch near Stoneybridge, S. Uist.

S. viminalis L. Osier.
Gt. Bernera, Valtos (L.), Harris, N. Uist, Benbecula and S. Uist; probably planted.

S. aurita L. Eared Sallow.
Generally wide-spread; moorlands, rocks, ravines, cliff ledges, sea banks etc.; only absent from one or two of the minor islands.

S. aurita × **S. repens.**
Gt. Bernera, Taransay, N. Uist, Eriskay, Vatersay and Mingulay.

S. atrocinerea Brot.
Not very common; sheltered cliffs of Gt. Bernera; near a stream, Breasclete, Lewis; south shore of East Loch Tarbert, Harris; Loch Olivat, etc., Benbecula; Abhainn Gheatry, on islands in several lochs etc., S. Uist; margin of Loch Obe and casually down the east of Barra to Castlebay.

S. atrocinerea × **S. repens.**
At the entrance to the Coire Dubh, S. Uist, and in the N.E. of Barra.

S. atrocinerea × **S. aurita.**
Abhainn Gheatry, S. Uist; North Bay, Barra; roadside, Benbecula.

***S. arbuscula** L. × **S. lapponum** L. (=**S. spuria** F.B.W.)
Ledge in Glen Skeaudale, N. Harris; determined by Kew as this hybrid.†

S. repens L. Creeping Willow.
Common and variable on every island except the Monach Isles and Fiaray, with the var. *argentea* from Barra. We have also critically determined the segregate *arenaria* from N. Uist and S. Uist.

***S. phylicifolia** L. Tea-leaved Willow.
Probably, for the most part, planted from Lochboisdale to Howmore although derived from native sources in the area between Loch Boisdale and Loch Eynort, S. Uist.

***S. Andersoniana** Sm. Dusky Sallow.
Very rare along streams near Bheinn Mhor, S. Uist.

***S. herbacea** L. Dwarf Willow.
Very rare on the summit crags of Crogary More (588 feet), but quite common at the top of Eaval (1138 feet), N. Uist: on all the mountains of the Bheinn Mor — Hecla group, S. Uist, also on Heaval and the adjacent heights, Barra.

Populus tremula L. Aspen.
Frequent on cliffs; Gt. Bernera, Little Bernera, Glen Valtos (L.); Harris; N. Uist; Taransay; Rueval, sea cliffs Loch Keiravagh, Oban Uaine etc., Benbecula; Allt Volagir, Hellisdale etc., S. Uist; Eriskay; Allt Heiker, Loch Obe, Ben Tangaval etc., Barra; Uidh, Heishival More, Vatersay; Cairn Galtar, Sandray; and cliffs, Mingulay Bay.

EMPETRACEÆ.

Empetrum nigrum L. Crowberry.
Locally common, heathy places; Lewis, Gt. and Little Bernera, Taransay, Harris, N. Uist, Benbecula, S. Uist, Muldoanich, and Barra; rare on Eriskay, Vatersay and Pabbay (B.).

†In my opinion this very tiny shrub is a Hebridean form of **S. lapponum** L. although I cannot exclude hybridity with absolute certainty. Ed.)

ORCHIDACEÆ.

***Malaxis paludosa** Sw.
South of Beinn Bheag Tuath, S. Uist, rare, but quite common south of Ben Rulibreck and scarce elsewhere on Vatersay.

***Listera cordata** Br. Small Twayblade.
Under heather Glen Valtos, Lewis; shores of Loch Baravat, Gt. Bernera; with *Hymenophyllum unilaterale* at the base of the cliffs facing Sythe Harbour, Taransay; North Lee and Eaval, S. Uist; ravines near Rueval, Benbecula; several points from Loch Eynort to Loch Skiport, S. Uist and in the Heaval area, Barra.

***L. ovata** Br. Twayblade.
Pasture near Uig Lodge, Uig Bay, Lewis; Daliburgh, S. Uist; here and there on Fuday; Barra and near Eorisdale, Vatersay.

Orchis mascula L. Early Purple Orchid.
Range not fully determined, but reported from grassy cliffs, Uig Bay, Lewis; cliff ledges, Corodale, Loch Eynort, S. Uist; Ben Tangaval, Tangusdale, Allt Heiker etc., Barra; scattered on Fuday; Am Meall, Bagh à Deas, Vatersay and on Sandray.

O. latifolia L. (sec. Pugsl.)
Well distributed from Lewis to Berneray (B.) in dune slacks, marshes and damp places; often very abundant, except on Mingulay, where it occurred rarely near the Keeper's House, and on Berneray (B.), where it was similarly uncommon near the landing place. Var. *coccinea* Pugsl. was collected on S. Uist, Barra, Vatersay, etc.

O. purpurella Stephenson.
Common and variable from Lewis to Mingulay. Var. *pulchella* Druce and intergrades occur.

O. purpurella × **O. latifolia.**
This hybrid was only found on Fuday.

***O. purpurella** × **O. Fuchsii** var. **hebridensis** (Wilm.) Heslop-Harrison.
Not rare with the parents on sandy ground near Loch St. Clair, Barra.

O. ericetorum (Linton) E. S. Marshall (=**elodes** Godf.)
Everywhere plentiful in the areas examined from Lewis to Berneray (B.).

O. ericetorum × **O. purpurella.**
Uig, Lewis; Great Bernera; cliffs, Tarbert, Harris; Taransay; base of Ben Tangaval, Borve etc., Barra; S. Uist and Benbecula.

***O. ericetorum** × **O. Fuchsii** var. **hebridensis.**
Common enough from Castlebay to Borve, Barra and on Vatersay.

***O. Fuchsii** Dr.
This species abounds from Benbecula to Mingulay and, in addition, we have it from the west of Lewis, but typical specimens are far from common. Of these latter we possess examples from Barra, Vatersay and S. Uist, with a few forms making the transition between the Hebridean variety and the type. The Hebridean development, var. *hebridensis* (Wilm.) Heslop-Harrison, was originally discovered by us, and subjected to critical study which demonstrated its relations with the type.

***O. majalis** Reichb. subsp. **occidentalis** Pugsl.
Only seen by us on Berneray (B.) at the landing place.

***Anacamptis pyramidalis** Rich. Pyramidal Orchid.
Abundant with the var. *fudayensis* Heslop-Harrison, on Fuday.

***Gymnadenia conopsea** Br.
This species occurred in Fuday on the moorlands, in the triangle formed by linking Corodale Bay, Rudha nan Eun and the summit of Mullach Neachel, as the var. *insulicola*† Heslop Harrison. This variety differs from the type in its lower stature, fewer flowers of a dull reddish purple colour and in the latter possessing a disagreeable smell recalling that of rubber. In our opinion this form ranks higher than a mere variety and should be regarded as a species under the name *G. insulicola* Heslop-Harrison. We defer final decisions until we study its cytology.

***Gymnadenia conopseo** var. **insulicola** × **O. Fuchsii** var. **hebridensis.**
Rare amongst heather to the east of Corodale Bay, Fuday.

***Leucorchis albida** Mey.
Rare; near Loch a' Chlachain, S. Uist.

Coeloglossum viride Hartm. Frog Orchis.
Not uncommon on grassy knolls, sea slopes etc. from Harris to Pabbay (B.), but very abundant on Berneray (B.) and Vatersay. The species varies greatly in flower colour and length of bract.

***C. viride** × **O. latifolia (incarnata).**
A hybrid new to the British islands; discovered with the parents on Berneray (H.).

***Platanthera bifolia** Reich. fil. Butterfly Orchid.
Only in Cas fo Dheas, S. Uist, and on Taransay.

IRIDACEÆ.

Iris Pseudacorus L. Iris.
Common in damp places, especially near the sea, and on the sites of old crofts, shielings etc., from Lewis to Barra Head.

LILIACEÆ.

***Allium ursinum** L. Garlic.
Sheltered places near rocks; Taransay; Ben Lee and Eaval, N. Uist; Loch Eynort etc., S. Uist; very rare, Am Meall, Vatersay.

Scilla verna Huds. Vernal Squill.
Sometimes plentiful in rocky places near the sea, Uig and Aird Uig, Lewis; then from Barra to Berneray (B.). On Sandray, Pabbay (B.) and Muldoanich it reaches the tops of their highest hills, thus attaining a height of 678 feet on Sandray.

S. non-scripta Hoffm. & Link. Bluebell.
Ledges amongst bracken, inland and near the sea; very local but often abundant on Harris, Taransay, N. Uist; Craigastrome to Lidistrome, Benbecula; east coast of S. Uist; north east of Barra as well as on Fuday (very rare) and some of the adjacent islets.

Narthecium ossifragum Huds. Bog Asphodel.
Plentiful everywhere on peaty ground, but not observed on the Monach Isles, Fiaray and Flodday.

†**Gymnadenia conopsea** Br. var. **insulicola** var. nov. (Heslop Harrison). Planta minor typo; flores roseo-purpurei, non suavolentes, (Type in collection H.-H.)

JUNCACEÆ.

Juncus bufonius L. Toad Rush.
Generally common in moist places on every island but Fuday.

J. squarrosus L. Heath Rush.
Very common; heathy places from Lewis to Mingulay although very local on Vatersay, Sandray, Pabbay (B.) and Mingulay.

J. Gerardi Lois.
Common, salt marshes and pools by rocks near the sea; on every island but Baleshare and Little Bernera.

***J. balticus** Willd.
Local on sandy ground near the sea; Valtos, Lewis; Uachdar, Benbecula; Baleshare; Pabbay (B.); Berneray (B.); Carnan to Stoneybridge, S. Uist.

J. effusus L. Soft Rush.
Here and there, moist ground from S. Uist to Pabbay (B.).

J. conglomeratus L. Common Rush.
Plentiful in places, but not on Monach Isles, Baleshare and Flodday.

***J. maritimus** Lam. Sea Rush.
Rare and local in salt marshes; Carinish, N. Uist; Loch Eynort, Carnan and Lochboisdale, S. Uist.

J. bulbosus L. Lesser Jointed Rush.
Common, pools and wet moorlands everywhere with the var. *fluitans* (Lam.) Dr. on N. Uist, Benbecula and S. Uist.

J. articulatus L. Shining-fruited Rush.
Common in moist places; on nearly every island.

J. acutiflorus Hoffm. Greater Jointed Rush.
Rather rare in wet places on Benbecula, S. Uist and Fuday.

***J. capitatus** Weigel.
Previously we have found this rush on Raasay and Rhum; now we record it from the sandy ground in the south west corner of Barra where it was certainly rare.

Luzula pilosa Willd.
N. Lee, N. Uist; Benbecula; S. Uist; Eriskay and Muldoanich; rather rare on rock ledges.

L. sylvatica Gaud. Great Hairy Wood Rush.
Occasionally common on sheltered and shady cliffs from Lewis to Sandray; on all the bigger islands as well as Taransay.

L. campestris DC. Field Wood Rush.
Frequent in grassy places everywhere except on Baleshare, Fiaray, Flodday and Pabbay (B.).

L. multiflora DC.
Common on damp moorland on every island except Pabbay (B.) and Flodday. The var. *congesta* Koch has been collected on the shores of Loch Cnuic, Gt. Bernera; cliffs on the summit of Eaval, N. Uist; Rueval area, Benbecula and S. Uist.

TYPHACEÆ.

***Sparganium neglectum** Beeby. Bur-reed.
Lochs near Stoneybridge etc., S. Uist and on Barra; not common.

***S. simplex** Huds. Unbranched Bur-reed.
Rare in lochs on Barra.

S. angustifolium Michx.
Local in lochs etc., Valtos, Lewis; Gt. Bernera; Taransay; Loch Fada, N. Uist; Benbecula; S. Uist; Eriskay and Barra.

LEMNACEÆ.

Lemna minor L. Lesser Duckweed.
Frequent in ditches etc.; Loch Sniogravat, Monach Isles; Berneray (H.); Liniclett, Borve, Benbecula; Stoneybridge etc., S. Uist; Eriskay; Fuday and Barra.

ALISMACEÆ.

***Baldellia ranunculoides** (L.) Parl.
Rather rare, slow streams and ditches; Loch Mor, Baleshare; Loch Sniogravat, Ceann Ear, Monach Isles; west of Benbecula; west of S. Uist; Barra and marsh near Caolis, Vatersay.

NAIADACEÆ.

Triglochin palustre L. Marsh Arrow-grass.
Common in marshy places on all the islands except the Monach Group, Baleshare, Fiaray and Muldoanich.

T. maritimum L. Sea Arrow-grass.
Abundant in salt marshes, but missing on Little Bernera, Fiaray, Muldoanich and Pabbay (H.).

Potamogeton natans L. Broad-leaved Pondweed.
Not rare in many lochs, pools etc. from Lewis to Sandray, including the Monach Isles, Gt. Bernera and Berneray (H.).

P. polygonifolius Pourr.
Plentiful in lochs, streams etc., on every island except Flodday.

***P. coloratus** Hornem.
Common enough in Loch na Liana Moire, Benbecula, and rare in a pool near Creagorry on the same island, also not rare in Loch Sniogravat on the Monach Isles.

***P. alpinus** Balb.
In lochans near Oban Uaine and near Nunton on Benbecula.

P. gramineus L.
Frequent, Berneray, Harris; Loch na Liana Moire etc., Benbecula; in many lochs from Howmore to Daliburgh, S. Uist; Loch St. Clair etc., Barra and Loch na Cuilce, Sandray.

*× **P. nitens** Weber (= **P. gramineus** × **P. perfoliatus**).
Little Loch Borve, Berneray (H.), loch near Uachdar, Benbecula, several lochs in the Stoneybridge district, S. Uist.

*× **P. Billupsii** Fryer (= **P. gramineus** × **P. coloratus**).
Quite common in Loch na Liana Moire, but rare in a loch on the roadside near Borve Castle, both on Benbecula.

*× **P. sparganifolius** Læstad. (= **P. gramineus** × **P. natans**).
Not rare in Loch na Liana Moire, Benbecula.

P. prælongus Wulf.
Rare in Loch Kearsinish etc., S. Uist.

P. perfoliatus L.
Not uncommon, Berneray, Harris; Loch Altabrug, lochs near Howmore, Loch Ollay etc., S. Uist; lochan near Loch Obe, Loch St. Clair, loch behind Heaval, Barra.

P. crispus L.
Not well distributed; Loch Bhruist and Little Loch Borve, Berneray (H.), loch near Bayhead, North Uist and Loch a' Mhachair, S. Uist.

***P. pusillus** L.
Lochs from Lochs Altabrug and Ollay to Loch Kildonan, S. Uist.

P. Berchtoldii Fieb.
Widespread and occasionally common; Little Loch Borve, Berneray (H.); Loch Mor, lochans near Creagorry and Borve Castle, Benbecula; Stoneybridge area, S. Uist; Lochan nam Faoileann, Barra.

P. pectinatus L.
Common in both fresh and brackish water lochs; Little Loch Borve, Berneray (H.), Loch Sniogravat, Monach Isles, Loch na Liana Moire, loch near Uachdar etc., Benbecula, Loch Ollay, Loch Altabrug etc., S. Uist, and Eoligarry, Barra.

P. filiformis Pers.
Not rare. Berneray, lochan near Uachdar and Borve Castle, Loch na Liana Moire etc., Benbecula; Lochs in Bornish. Howmore, Stoneybridge areas, S. Uist; Loch St. Clair, Barra.

*× **P. suecicus** Richt. (= **P. filiformis** × **P. pectinatus**).
Locally with the parents; Little Loch Borve. Berneray (H.), Loch na Liana Moire, lochans near Borve Castle and Uachdar, Benbecula.

***Ruppia maritima** L. (= **spiralis** Hartm.)
Stream near Craigastrome, Benbecula.

***R. rostellata** Koch.
Lochs Altabrug and Ceann a' Bhaigh, S. Uist; probably also near Lochmaddy, N. Uist.

***Zannichellia palustris** L. Horned Pondweed.
In Loch Sniogravat, Monach Isles, and near Lochboisdale, S. Uist.

***Z. pedunculata** Reich.
Loch near Borve Castle, Benbecula.

Zostera marina L. Grass Wrack.
Washed ashore on Taransay, Berneray (H.), North Uist, Baleshare, S. Uist, Fuday and Barra.

***Naias flexilis** Rostk. & Schmidt.
Abundant in various lochs between Howmore and Stoneybridge, S. Uist.

CYPERACEÆ.

Eleocharis palustris Roem. & Schult.
Common marshes, shallow water etc.; every island except Pabbay (H.), Baleshare, Flodday and Muldoanich.

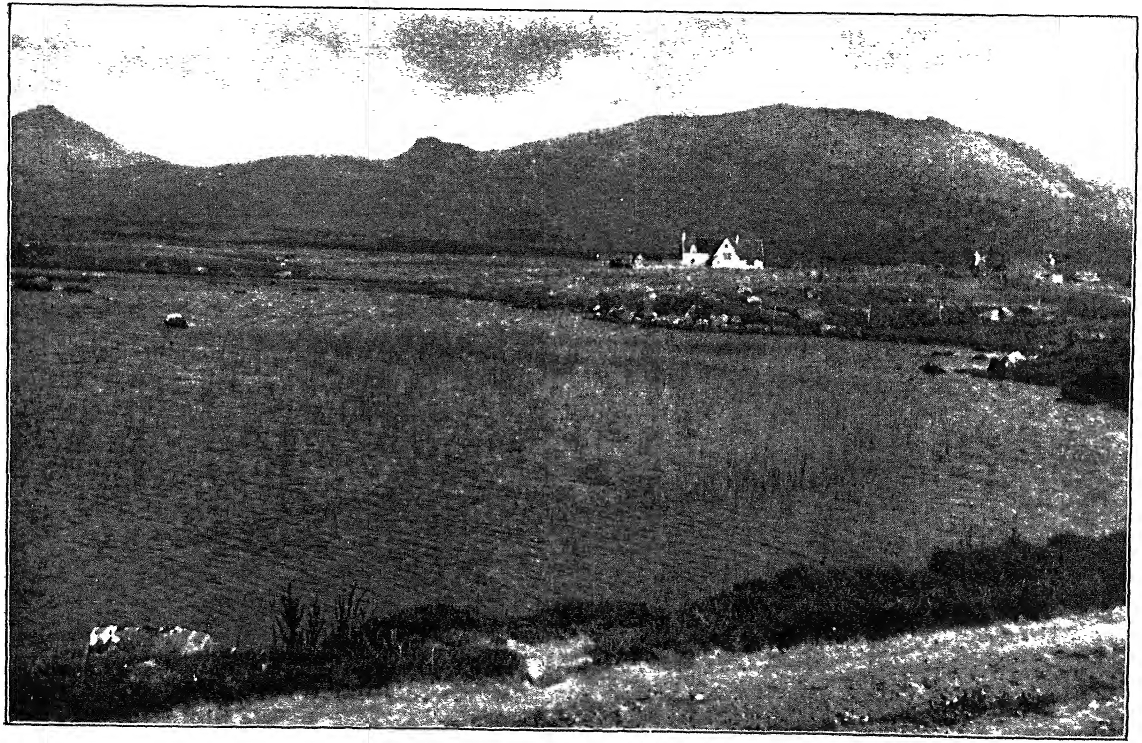
***E. uniglumis** Schult.
Rare, marshes near the sea in the west of Benbecula and S. Uist, and on Flodday.

E. multicaulis Sm.
Quite common, bogs, moorlands etc.; on all the islands but Fuday and Flodday, with a viviparous form on Vatersay.

Scirpus pauciflorus Lightf.
Locally plentiful in marshes etc. from Lewis to Pabbay (B.).

S. cæspitosus L.
Abundant throughout the "Long Island" on moorlands.

S. fluitans L.
Common enough in streams, lochs, etc.



(*Photo by W. A. Clark*).
Fig. 6. Beinn Mhor, Feaveallach, Hecla Group from Stoneybridge, showing one of the lochs in which *Naias flexilis* grows.

***S. pygmæus** (Vahl.) A. Gray (=**S. Savii** Seb. & Maur.)
Here and there; common in wet places near the sea on Barra, Fuday, Vatersay and Pabbay (B.).

S. setaceus L.
Local, on wet ground from Lewis to Mingulay, although not seen on B.H., P.H., Mo., N.U., Benb., Pabbay (B.) and the smaller rocky islets.

***S. lacustris** L. Bulrush.
Near Loch Skiport, S. Uist only.

***S. Tabernæmontani** Gmel.
Occasionally in streams and lochs near the sea; Loch Laxadale, Harris; loch between Carinish and Eaval, N. Uist; Borve, Nunton etc., Benbecula; Loch Skiport to Daliburgh, S. Uist; and Barra.

S. maritimus L. Sea Club Rush.
Salt marshes and pools near the sea but not well distributed; near the beach Tobson, Gt. Bernera; western districts of Benbecula; S. Uist and Barra; also on Fuday and Pabbay.

***Blysmus compressus** (L.) Panz. ex Link.
Only collected near Daliburgh, S. Uist.

B. rufus Link.
Frequent in salt marshes; Uig (L.), near ferry Gt. Bernera, Loch Borve (B.H.), Uachdar to Borve (Ben.); Carnan to Pollachar (S.U.); Barra and Fuday.

Eriophorum vaginatum L. Cotton Grass.
Not very common, but scattered in peat bogs from Lewis to Barra; only seen on Taransay and Berneray (H.) amongst the smaller isles.

E. angustifolium Roth. Common Cotton Grass.
Very abundant; on every island, in bogs etc., from Lewis to Berneray (B.), except the Monach Group.

Rynchospora alba Vahl. White Beaked Sedge.
Locally very common; bogs between Maari and Lochmaddy, N. Uist; moorlands around Rueval, Benbecula; base of Beinn Mhor group, Sheaval etc., S. Uist; rare, south of Lochan nam Faoilleann, etc., Barra.

Schœnus nigricans L. Black Bog Rush.
Very abundant, more especially near the sea on all the islands but L.B., Bal., Mo. and Fy.

***Cladium Mariscus** Br. Prickly Rush.
Exceedingly rare in lochs; Loch Fada near Eaval, N. Uist; lochan on Eriskay.

Carex dioica L. Dioecious Sedge.
Uig (Lewis), Little Bernera, Harris, Pabbay (H.), Berneray (H.), and then frequent on bogs and heaths from Benbecula to Pabbay (B.).

***C. pulicaris** L. Flea Sedge.
Common on damp ground from Lewis to Berneray (B.).

***C. rupestris** All.
Very rare on the rocky ridge near the summit of Beinn Mhor, S. Uist.

***C. pauciflora** Lightf.
Rare and local between Sheaval and Trinival, S. Uist.

C. arenaria L. Sand Sedge.
Abundant everywhere on sand dunes except Fiaray, Flodday, Muldoanich and Berneray (B.).

***C. maritima** Gunn. (=**C. incurva** Lightf. var. **erecta** Lang.)
Locally frequent in a few damp hollows in the machair on Berneray (H.).

***C. paniculata** L. Tussock Sedge.
Plentiful in a marsh near Nunton, Benbecula.

C. Otrubæ Podf. (=**C. vulpina** L.) Fox Sedge
Occasionally in rocky places by the sea; Barra, Fuday, Vatersay and Pabbay (B).

***C. Pairæi** F. Schultz.
Rare, north west of Heishival toward Traigh Varlish, Vatersay; the second Scottish record.

C. echinata Murr. Starry Sedge.
Abundant in moorland bogs from Lewis to Berneray (B.).

C. remota L.
Only on a stream running into Loch Eynort on the south shore, S. Uist.

***C. curta** Good. White Sedge.
Only in a shallow gorge, north west of the ruins on Pabbay (B.).

C. ovalis Good. Hare's Foot Sedge.
Somewhat sparsely scattered in grassy places, paths etc. on practically every island from Lewis to Pabbay (B.).

***C. Hudsonii** Ar. Benn.
Only on the moor near the Pier, Gt. Bernera, Lewis.

***C. rigida** Good.
Locally plentiful on the summit rocks of Eaval, N. Uist and Beinn Mhor, S. Uist.

C. Goodenowii Gay.
Generally abundant on all the islands visited. The var. *juncea* Fr. was found in the Croir district in the north of Gt. Bernera.

C. flacca Schreb. Glaucous Sedge.
Common in grassy places everywhere from Lewis to Mingulay.

***C. Halleri** Gunn.
Rare, summit cliffs of Eaval, N. Uist.

***C. limosa** L.
Rare generally, but sometimes locally plentiful; Glen Valtos, (Lewis); loch near Sandavat, Gt. Bernera; Little Bernera; Taransay; Loch Iarras, Coire Dubh etc. (S.U.) and Sandray.

***C. rariflora** Sm.
Exceedingly rare amongst rocks on the upper ridge of Beinn Mhor, S. Uist.

C. pilulifera L. Pill Sedge.
Common on steep slopes and rock ledges, especially on higher ground, Glen Valtos (Lewis); Gillaval Glas, (Harris); Eaval, (N. Uist); Benbecula, S. Uist, Barra and Vatersay.

***C. caryophyllea** Latour. Vernal Sedge.
Rare in dry rocky places; Vatersay and Pabbay (B.).

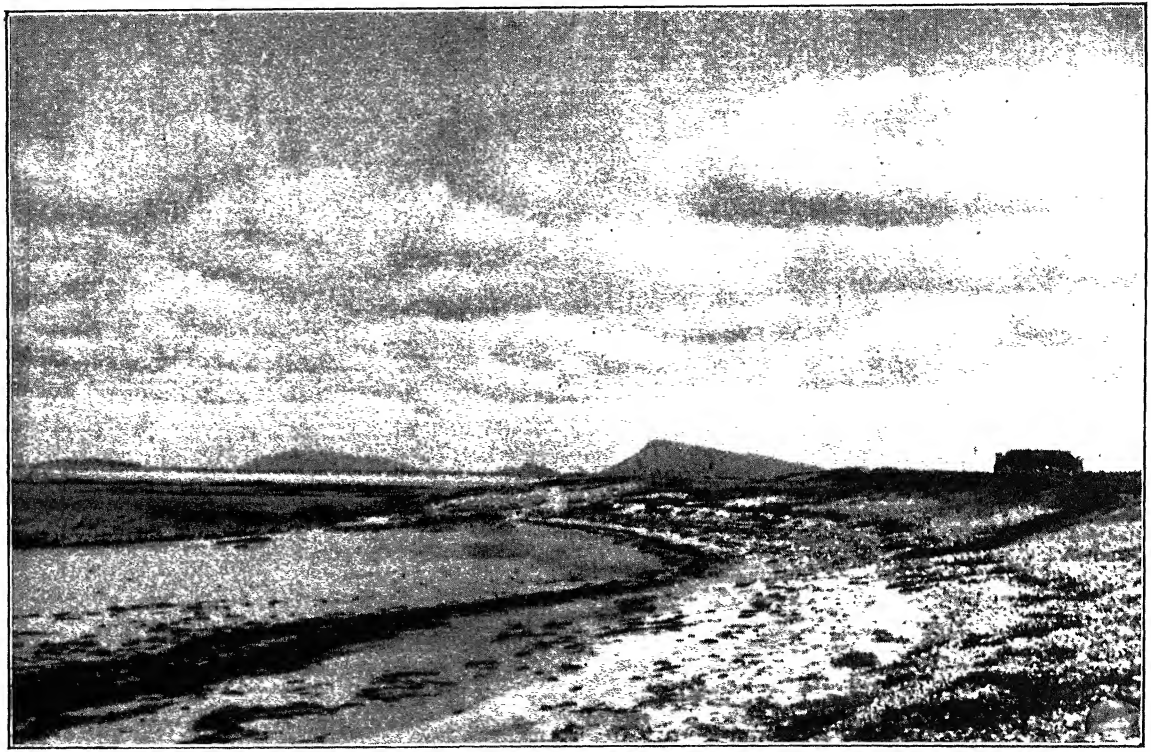
***C. pallescens** L. Pale Sedge.
Rare and local on sunny rock ledges on the northern shores of Loch Eynort and Loch Boisdale, S. Uist.

C. panicea L. Carnation Grass.
Very common in bogs, etc.

***C. vaginata** Tausch.
Rare in the Black Corrie on Beinn Mhor, S. Uist.

C. binervis Sm.
Abundant on moorlands everywhere, except B.H., Bal., Mo., Fy., Fl., and B.B.

C. distans L. Distant Spiked Sedge.
Frequent from Uig (Lewis) to Mingulay but, curiously enough, not seen on Barra.



(*Photo. by W. A. Clark*).

Fig. 7. Eaval, North Uist, the abode of *Carex Halleri*, from Benbecula.

C. Hostiana DC. Tawny Sedge.
Common on marshy ground on most of the islands.

C. Hostiana × **C. demissa.**
Muldoanich; near Loch Heddal More, Pabbay (H.); Moor Hill, Berneray (H.).

C. extensa Good.
Occasionally, rocky places beside the sea; Pabbay (H.), Fuday, Fiaray, Flodday, Vatersay, Sandray and Pabbay (B.).

C. lepidocarpa Tausch.
Frequent on moist ground; from Lewis to Vatersay, although we have no Barra records.

C. lepidocarpa × **C. demissa.**
Heaval etc., Barra.

C. lepidocarpa × **C. Hostiana.**
Occasionally wherever the two overlap.

***C. subglobosa** Miel. (=**C. Oederi** auct.)
Very local on the stony margins of lochs, but not uncommon where it exists; Glen Valtos, Lewis; Loch a' Chnuic, Gt. Bernera; and central S. Uist.

C. demissa Hornem. (=**C. Oederi** var. **œdocarpa** And.)
Common in damp places everywhere.

***C. demissa** × **C. extensa.**
A plant, almost certainly of the parentage just stated, was obtained on Flodday.

C. rostrata Stokes. Bottle Sedge.
Locally very plentiful on the margins of peaty lochs, slow streams etc. from Lewis to Vatersay.

***C. vesicaria** L. Bladder Sedge.
Rare, lochs in the Howmore district, S. Uist.

GRAMINEÆ.

***Phalaris arundinacea** L. Reed Grass.
Ditch near Caranish, N. Uist.

Anthoxanthum odoratum L. Sweet Vernal Grass.
Very common in grassy places from Lewis to Berneray (B.).

Alopecurus geniculatus L. Fox-tail.
In damp places everywhere from Lewis to Berneray (B.).

***A. pratensis** L. Meadow Fox-tail.
Extremely rare in the Outer Isles; only along a road side near the Post Office, Callanish, Lewis.

***A. alpinum** L. Alpine Fox-tail.
Very rare; amongst rocks, Beinn Mhor, S. Uist.

***Phleum pratense** L. Timothy.
Rare; Uig (L.), Bayhead (N.U.); roadside between Balevanish and Nunton, (Ben.); Stoneybridge (S.U.); and Little Bay (B.).

***Muhlenbergia racemosa** Michx.
A casual of American origin, Castlebay, Barra.

Agrostis canina L. Brown Bent.
Very common on all the islands with the alpine var. *scotica* Hackel on Feaveallach.

A. stolonifera L. White Bent.
Common on all the islands, with var. *aristata* Sincl. on Mingulay.

A. tenuis Sibth. Fine Bent.
Common in heathy places except on Flodday, with the var. *pumila* L. on pathways etc. on Benbecula, S. Uist, Barra, Taransay and Berneray (H.).

Ammophila arenaria (L.) Link. Marram.
On every island, even the rocky islets, except Muldoanich.

Aira caryophyllea L. Silver Hair Grass.
Never really common; roadways, dry banks etc., Uig (Lewis), Lochmaddy (N.U.), Berneray (H.), Howmore (S.U.) and Eriskay.

A. præcox L. Early Hair Grass.
Walls and old crofts on every island.

***Deschampsia cæspitosa** (L.) Beauv. Tufted Hair Grass.
Very local in sheltered places on high ground; Callanish (L.), Cnoc Eadar Dà Bheinn and Clisham (H.), Taransay, North Uist, Beinn Mhor, Hecla (S.U.), gully near Lochan nam Faoileann (B.), Vatersay, Muldoanich and Pabbay (B.).

***D. alpina** Rœm. and Schult.
Not uncommon, rock ledges on Beinn Mhor and Hecla, S. Uist.

***D. setacea** Richter.
Locally common around the edges of lochs; Loch a' Cnuic, Ruig, Sandavat etc., (G.B.); Loch Heddal More (P.H.); pools near Loch Bruist in the Bayhead area (N.U.); Benbecula; in many lochs south of Loch Skiport and off Loch Eynort Road, (S.U.).

D. flexuosa Trin. Wavy Hair Grass.
In shelter places, never very plentiful, from Lewis to Berneray (B.); the var. *montana* Hook fil. grows at a height of 1500 feet on Feaveallach, S. Uist and a very large form in a gully at Balnabodach, Barra.

***Holcus mollis** L. Soft Grass.
Rare, often amongst bracken and on sheltered ledges; Taransay, Harris, dun in loch near Eaval (N.U.); side of School Path, Benbecula; Meall Mhor, S. Uist; Eriskay and Barra.

H. lanatus L. Yorkshire Fog.
Everywhere common enough.

Avena pubescens Huds. Downy Oat.
On grassy ledges and slopes near the sea from Lewis to Berneray (B.), but not regularly distributed.

A. strigosa Schreb. Black Oat.
As an escape from cultivation on many of the islands.

A. fatua L. Wild Oat.
Of infrequent occurrence as a weed; Valtos (L.), Tobson (G.B.), Berneray (H.), Risgarry (N.U.) and Eriskay.

Arrhenatherum elatius Mert. & Koch. False Oat.
Fairly common from Lewis to Mingulay.

A. tuberosum Gilib.
Cultivated ground, waste places etc.; L., G.B., H., T., Mo., N.U., Ben., S.U., E., and Barra.

Sieglingia decumbens Bernh. Heath Grass.
Common on moorlands everywhere except on the Monach Isles.

Phragmites communis Trin. Common Reed.
In lochs and wet places, common, from Lewis to Barra Head; missing from Mo., Bal., and P.H.

Cynosurus cristatus L. Crested Dog's Tail.
Plentiful on all the islands save Muldoanich.

Koeleria gracilis Pers.
Grassy situations generally, as var. *britannica* Domin.

Molinia cærulea Mœnch. Purple Moor Grass.
A common component of moorland, and moor slack vegetation, except on the Monach Group.

Catabrosa aquatica Beauv. Water Whorl Grass.
Common in wet sandy places near the sea, especially on stream edges; from Uig, Lewis to Sandray.

***Dactylis glomerata** L. Cock's-foot.
Only common at Callanish, Lewis; rare Uig, Lewis; Church grounds near Breaclete, Gt. Bernera; Bayhead and Lochmaddy, N. Uist; Benbecula; Ormaclett Castle and Lochboisdale, S. Uist; Barra and Vatersay.

Poa annua L. Annual Meadow Grass.
Very common on all the islands.

***P. alpina** L.
Very rare on ledges in Allt Volagir, S. Uist.

P. pratensis L. Smooth-stalked Meadow Grass.
Common from Lewis to Berneray (B.). The var. *subcærulea* Sm. was collected freely on the dunes at Uig, Lewis, and in Berneray (H.), Fuday and Barra, whilst the var. *strigosa* Gaud. was noted on the Pabbay (B.) dunes.

***P. palustris** L.
Not well distributed and generally growing amongst Irises; Valtos and Callanish, Lewis; Pabbay (H.); Berneray (H.); Stoneybridge to Howmore, S. Uist and Eriskay.

P. trivialis L. Rough Meadow Grass.
Generally common from Lewis to Berneray (B.).

Glyceria fluitans Br. Floating Meadow Grass.
Common in ditches and wet places on all the islands except L.B., F., Fy., P.B., S., Mul., and M. Viviparous forms were gathered near Bornish, S. Uist.

Puccinellia maritima Huds. (Parl.) Sea Meadow Grass.
Plentiful in salt marshes on every island presenting suitable stations.

***Catapodium loliaceum** (Huds.) Link.
Not uncommon on sand dunes, old walls and crofts etc. from Lewis to Pabbay (H).

***Vulpia bromoides** (L.) S.F.G. Barren Fescue.
In a dry ditch on the south side of Loch Eynort, S. Uist and near the shop, Eriskay.

Festuca ovina L. Agg. Sheep's Fescue.
Abundant on moorlands, rocks etc. from Lewis to Berneray (B.).

Var. **genuina** Gren. & Godr.
Common everywhere in the proliferated condition.

Var. **hispidula** (Hack.) Richt.
Also always in the viviparous condition; Feaveallach, S. Uist; Allt Heiker, Barra; Pabbay (B.); generally on rock ledges.

F. rubra L. Agg. Red Fescue.
Common everywhere; hilly areas near the sea etc.

Var. **vulgaris** Gaud.
Common from Lewis to Mingulay.

Var. **glaucescens** (Hegets & Heer.) Richt.
Generally on rocks near the sea; distribution much as the preceding.

Var. **dumetorum** (L.) Howarth.
On Feaveallach, S. Uist at 1500 feet.

Var. **arenaria** (Osp.) Fr.
Not uncommon on the edges of sand dunes, but in a ravine on Muldoanich. Found on S. Uist, Eriskay, Barra, Fuday, Fiaray, Vatersay, Sandray, Muldoanich and Pabbay (B.).

***F. prolifera** (Piper) Fernald.
Cliffs Tarbert, Harris, and in the big ravine issuing from the Coire Dubh, Beinn Mhor, S. Uist. (See below!)

***F. glauca** Lam.
Widely scattered in the Hebrides; occasionally, as in the Isle of Coll (v.-c. 103), forming a very conspicuous feature of the moorland vegetation even to sea level. In v.-c. 110 on Lewis (Glen Valtos); cliffs Tarbert, S. Harris; Benbecula; moorlands under the mountains, S. Uist; Lochan nam Faoileann, Barra. The Hebridean form is always proliferous and is named below apm. *hebridensis* Heslop-Harrison.

[We have presented above an account of our *Festuca ovina-rubra-glauca* collections as determined by Dr. W. O. Howarth. Nevertheless, we feel that in the case of apomicts it does not convey a satisfactory view of the Hebridean populations. For instance, no one can carry out a field study of the proliferated forms assembled under the name "*Festuca ovina* var. *genuina*" without realizing that there is under survey a series of strikingly different biotypes. These remain constant over large areas, are genetically distinct and reproduce themselves. Recognising these facts amongst his material, Turesson (*Hereditas*, Vol. VIII, pp. 161-206) has placed the matter on a sound basis and in doing so has developed a reasonable classification of the various viviparous forms. In it the viviparous biotypes, known to be obligatorily apomictical, are designated "apomicts," and it is pointed out that these are strictly parallel with socalled "species" in Hieracium, Rosa, etc. Amongst our *Festuca ovina* collections we have recognised the following apomicts:—

***Festuca ovina** L. apm. **færœnsis** Turesson.
Widely spread; ravine of Abhainn Gheatry, S. Uist; Lochan nam Faoileann and Allt Heiker, Barra.

***Festuca ovina** L. apm. **scotica** Turesson.
Scattered from Lewis to Mingulay.

***Festuca ovina** L. apm. **norvegica** Turesson.
Generally on higher ground than the preceding and thus further from the sea; S. Uist to Pabbay (B.)

Festuca rubra L.
In this case we feel certain that *F. prolifera* Fernald, whilst structurally different in other points than its vivipary from typical *F. rubra*, takes its place correctly as an apomict of *F. rubra*.

Festuca glauca L.
Similarly, the form of this species in the Outer and Inner Hebrides represents a distinct, truly breeding, apomictical biotype which is now supplied with a name modelled on the lines of those employed by Turesson in dealing with his chain of *F. ovina* apomicts.

Festuca glauca Lam. apm. **hebridensis** Heslop-Harrison.
Forma vivipara. (Type from the Isle of Coll and now in the Heslop-Harrison collection.)]

F. elatior L. Meadow Fescue.
Stream sides, wet pastures etc.

*Subsp. **pratensis** (Huds.) Hack.
Rather rare; pastures Stoneybridge, S. Uist; Eoligarry, Barra and on Taransay.

*Subsp. **arundinacea** (Schreb.) Hack.
This occurred as the subv. *strictior* Hack. of var. *genuina* Syme; Taransay (west dunes), Nunton, Benbecula; Eoligarry, Barra and on Uinessan, Vatersay.

Bromus hordeaceus L. Soft Brome.
Common everywhere as a weed on arable land and in waste places.

***Brachypodium sylvaticum** Beauv. False Brome.
Rare, especially as one passes northward in the Isles, on cliff ledges and similar stations; cliffs near Bosta, Great Bernera; Benbecula; South Uist; gully on road to Lochan nam Faoileann, Barra; Muldoanich, Vatersay, Sandray, Pabbay (B.) and Mingulay.

Lolium perenne L. Rye Grass.
Not very plentiful from Berneray (H.), to Berneray (B.)

L. multiflorum Lam.
Edge of School Path, Benbecula; Brevig, Barra; always introduced.

Agropyron repens Beauv. Couch Grass.
Not uncommon on waste land and shingle; from Lewis to Sandray, but not noted on the smaller rocky isles.

A. junceum Beauv. Jointed Couch Grass.
Not uncommon on sand dunes on all the islands except Sandray and Muldoanich. The var. *megastachyum* Beauv. was collected on T., H., Bal., Mo., N.U., S.U., B., F., Fy., V., M. and B.B.

Nardus stricta L. Mat Grass.
Not uncommon on the moorlands of every island except the Monachs, Fiaray, Fuday and Flodday.

CONIFERÆ.

***Juniperus communis** L. var. **intermedia** Nym. Juniper.
Rare in sunny rocky places; Craigstrome, etc., Benbecula, east coast, S. Uist and Barra.

J. sibirica Burgsdorf.
Heathy rocky places; abundant on Muldoanich, locally frequent, Lewis (Glen Valtos), Gt. and Little Bernera, Harris, N. Uist, Benbecula, S. Uist, and Barra; rare, Taransay, Eriskay, Vatersay, and Pabbay (B.).

(**Pinus sylvestris** L. Scots Pine.
We have seen quite large stumps of this, and of the Silver Birch, taken from the peat and have been told they occur likewise in submerged forests off S. Uist.)

FILICES.

***Hymenophyllum peltatum** Desv. Filmy Fern.
Wet rocks, and often sheltered by heather; Glen Valtos (L.), L.B., T., H., N.U., P.H., Ben., S.U., E., B., V., Mul., S. and P.B. It is very abundant on the northern face of Beinn Mhor, S. Uist.

Pteridium aquilinum Kuhn. Bracken.
Abundant on S. Uist and at places on Barra; more local on Lewis and Harris, and southward to Berneray (B.).

***Cryptogramme crispa** R.Br. Parsley Fern.
Exceedingly rare and local; Beinn Mhor, S. Uist.

Blechnum Spicant With. Hard Fern.
Common in heathy places everywhere except on Mo., Bal., B.H., Fl. and Fy.

Asplenium Adiantum-nigrum L.
Common in rock crevices from Lewis to Pabbay (B.); not, however, on Mo., Bal., Fl. and Fy.

A. marinum L. Sea Spleenwort.
Locally abundant on sea cliffs on every island except Mo., B.H., Fy. and Fl.

A. Trichomanes L. Black Spleenwort.
Occasionally on inland cliffs from Lewis to Vatersay.

***A. Ruta-muraria** L. Wall Rue.
Rare; rocky exposures on dunes Uig, Lewis; inland cliffs S. Uist and Fuday.

Athyrium Filix-fœmina Roth. Lady Fern.
Abundant, shady places, on all the islands but Mo., Bal., F., Fl., Fy., M. and B.B.

***Phyllitis Scolopendrium** Newm. Hart's Tongue Fern.
Very rare; sheltered banks of a streamlet near Dun Chlach, Taransay and on island cliffs, Sandray; probably as an escape on a wall, Lochmaddy, N. Uist.

***Cystopteris fragilis** Bernh. Brittle Bladder Fern.
Rare and local, cliffs, Beinn Mhor, S. Uist.

***Polystichum lobatum** Wayner. Hard Shield Fern.
Very rare; near Hart's Tongue Fern, Taransay, as well as on S. Uist and Eriskay.

Dryopteris Oreopteris Max. Mountain Buckler Fern.
Fairly plentiful in sheltered mountain gullies, Benbecula, S. Uist and Barra.

D. Filix-mas Schott. Male Fern.
Abundant in protected stations on most of the islands southward to Sandray, but rare south of Barra.

D. spinulosa O. Kuntze. Narrow Buckler Fern.
Generally rare but widespread from Lewis to Sandray.

D. dilatata A. Gray. Broad Buckler Fern.
Common in sheltered places; Pabbay (H.), Benbecula, S. Uist and Barra, but becoming very scarce on Vatersay, Muldoanich and Sandray.

***D. æmula** O. Kuntze. Scented Buckler Fern.
Occasionally in sheltered nooks; Taransay; North Lee, N. Uist; Benbecula; S. Uist; Barra and Muldoanich.

***D. Phegopteris** C.Chr. Beech Fern.
Rare in sheltered ravines; Glen Valtos, Lewis; Clisham, N. Harris; Eaval, N. Uist; mountain massif, S. Uist and Barra.

Polypodium vulgare L. Common Polypody.
Common on cliffs everywhere except Mo., Bal., F., Fl., Fy. and B.B.

Osmunda regalis L. Royal Fern.
Locally frequent on stream and loch sides, as well as on islets in the lakes, from Lewis to Mingulay; not seen on the more rocky islets.

Ophioglossum vulgatum L. Adder's Tongue.
Locally abundant on dune, pasture and machair from Pabbay and Berneray (Harris) to Mingulay, although we did not see it on Fiaray, Flodday, Muldoanich and Sandray.

Botrychium Lunaria Sw. Moonwort.
Occasionally abundant on the machair etc.; Uig (L.), G.B., L.B., T., P.H., B.H., Ben., S.U., E. and B.; much rarer on Fuday and Vatersay.

EQUISETACEÆ.

Equisetum arvense L. Common Horse Tail.
Common on sand dunes, pastures etc., on most of the islands.

***E. pratense** Ehrh.
Rare and local, near Loch Ollay, S. Uist.

E. sylvaticum L. Wood Horse Tail.
Rare on shady banks, Earshader, Lewis, Harris, S. Uist, Barra, Vatersay, Sandray, Muldoanich and on the Bay, Mingulay.

E. palustre L. Marsh Horse Tail.
Abundant in marshes everywhere except Fiaray, Muldoanich, Flodday, Baleshare, and Gt. and Little Bernera.

E. limosum L. Smooth Water Horse Tail.
Abundant in lochs etc. from Lewis to Vatersay, but not on any of the small islands. The var. *fluviatile* L. was collected on S. Uist.

***E. variegatum** Schleich.
The var. *arenarium* Newm. occurred on a wet exposure, Nisabost Point, S. Harris.

LYCOPODIACEÆ.

Lycopodium Selago L. Fir Club Moss.
Rather rare in inland rocky places; Harris, Taransay, Pabbay (H.), N. Uist, Benbecula (Rueval), S. Uist, Eriskay, Barra and Vatersay.

SELAGINELLACEÆ.

Selaginella Selaginoides Gray.
Very abundant, amongst moist short turf and in sandy places on every island except the Monach Isles, Baleshare and Fiaray.

Isœtes lacustris L. Quillwort.
Loch bottoms; Loch Tana, Gt. Bernera; Loch Shealtar, N. Uist; but frequent in the same type of locality on S. Uist.

CHAROPHYTA.

Chara delicatula Agardh.
Common in streams etc.; Vatersay and Sandray.

C. globularis Thuill. (=**C. fragilis** Desv.)
Lochs etc. on S. Uist.

C. aspera Willd.
Loch Ollay etc., S. Uist.

C. hispida L.
Rare in lochs; Benbecula and S. Uist.

C. vulgaris L.
Loch Ollay and others near Daliburgh, S. Uist, Fuday, Vatersay; both aquatic and semi-terrestrial forms were examined.

Nitella translucens Agardh.
Rare; Sandray.

N. opaca Agardh.
Occasionally in lochs; Benbecula and S. Uist.

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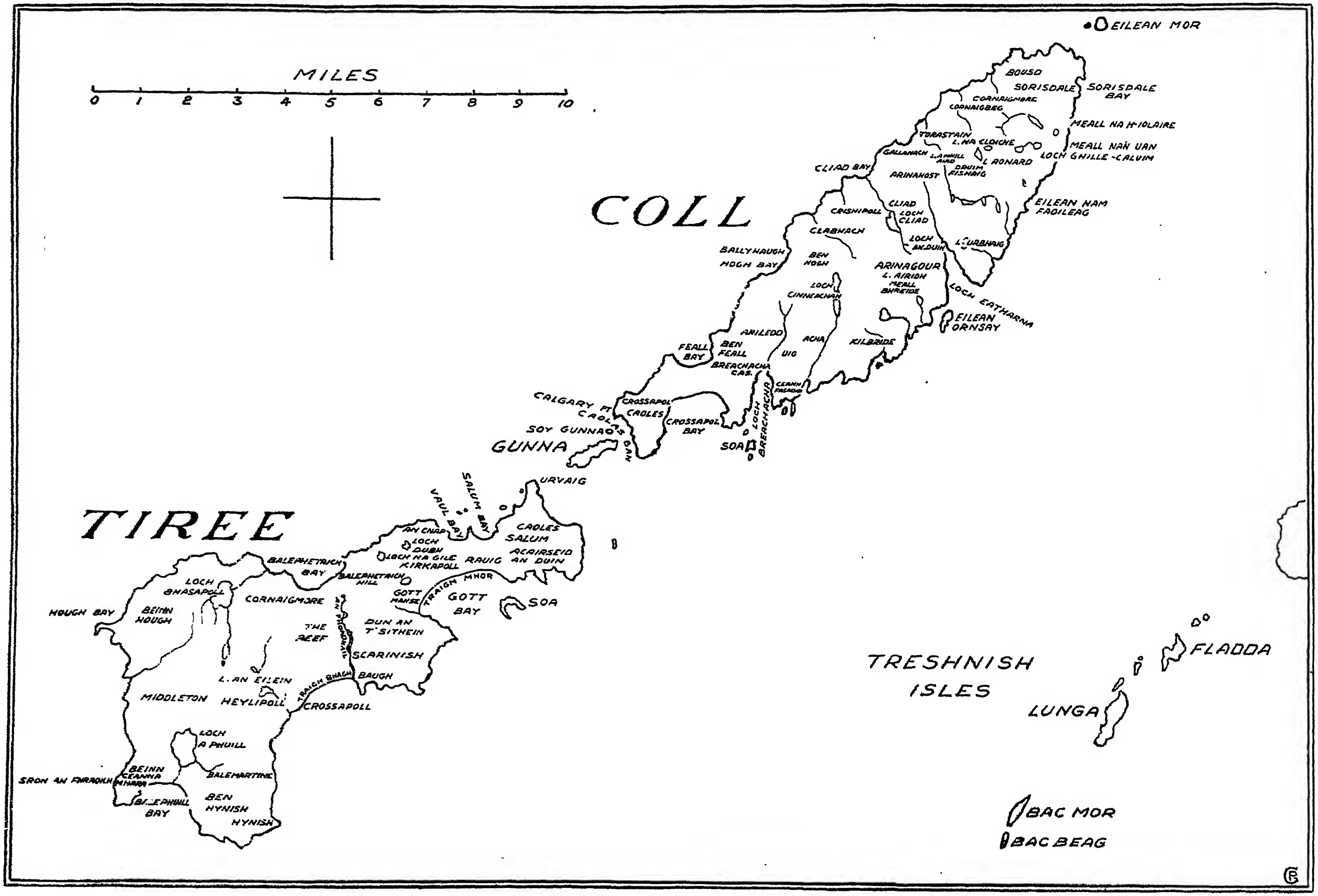
MILES
0 1 2 3 4 5 6 7 8 9 10
COLL
TIREE
EILEAN MOR
BOUSO
SORISDALE
SORISDALE BAY
CORNAIGMORE
CORNAIGBEG
MEALL NA H-IOLAIRE
MEALL NAN UAN
LOCH GHILLE-CALUIM
TORASTAIN
L. NA CLOICHE
GALLANACH
L. RONARD
DRUIM FISHAIG
CLIAD BAY
ARINAHOST
EILEAN NAM FAOILEAG
CRISHIPOLL
CLIAD
LOCH CLIAD
CLABHACH
LOCH AN DUIN
BALLYHAUGH
HOGH BAY
BEN HOGH
ARINAGOUR
L. AIRIDH
MEALL BHREIDE
LOCH CINNEACHAN
LOCH EATHARNA
EILEAN ORNSAY
ARILEOD
ACHA
KILBRIDE
FEALL BAY
BEN FEALL
UIG
BREACHACHA CAS.
LOCH BREACHACHA
CALGARY PT
CAOLAS
CROSSAPOL
CAOLES
CROSSAPOL BAY
SOY GUNNA
GUNNA
SOA
URVAIG
VAUL BAY
SALUM BAY
AN CNAP
LOCH DUBH
LOCH NA GILE
KIRKAPOLL
RAUIG
CAOLES
SALUM
ACAIRSEID AN DUIN
BALEPHETRICH BAY
BALEPHETRICH HILL
LOCH BHASAPOLL
CORNAIGMORE
GOTT MANSE
TRAIGH MHOR
GOTT BAY
SOA
HOUGH BAY
BEINN HOUGH
THE REEF
AN FHAODHAIL
DUN AN T'SITHEIN
SCARINISH
L. AN EILEIN
TRAIGH BHAGH
BAUGH
MIDDLETON
HEYLIPOLL
CROSSAPOLL
LOCH A PHUILL
BEINN CEANNA MHARA
SRON AN FHAROIKH
BALEMARTINE
BALEPHUILL BAY
BEN HYNISH
HYNISH
TRESHNISH ISLES
FLADDA
LUNGA
BAC MOR
BAC BEAG

THE FLORA OF THE ISLES OF COLL, TIREE AND GUNNA (V.-C. 110B).

By

J. W. Heslop Harrison, D.Sc., F.R.S., Helena Heslop Harrison, M.Sc., W. A. Clark, B.Sc., Ph.D., and R. B. Cooke.

In 1934, when the task of preparing a Flora of the Inner and Outer Hebrides was first undertaken by the Department of Botany, King's College, University of Durham, it was realized almost immediately that the Isles of Coll and Tiree would play a major part in linking the Outer Island investigations with those carried out on the Inner Isles. Hence, at the earliest possible date, Dr. G. Heslop Harrison was dispatched to carry out a preliminary examination of the group. His reports were so encouraging that, not only did he return to Coll in the spring of 1937 to extend his observations, but, in addition, accompanied by Dr. W. A. Clark, he paid a visit in the summer of the same year.

Next, during the seasons of 1939 and 1940, the authors of this paper spent three lengthy periods on Coll and Tiree, thereby adding greatly to our knowledge of the critical plants and of their distribution. On the second of these occasions, advantage was taken of our stay on Tiree to explore the Isle of Gunna. Again, for additional results secured during the earlier of these two years we have to recognize the unstinted efforts of a party of our students comprising Mr. J. Heslop Harrison, Mr. G. E. M. Hardy, Mr. C. S. Pittendrigh and Mr. J. A. Richardson, who camped on Coll. Their work was noteworthy for several reasons, firstly, because they broke new ground on the Isle of Gunna, and, secondly, because they made some extraordinary discoveries on Coll, which included such novelties as *Spiranthes Romanzoffiana (stricta)* and *Trifolium Bocconi*.

Tiree and Coll are orientated roughly in a north-east and south-west direction to the west of the Isle of Mull from which they are separated by a strait, which, at its narrowest point, between Loch Eatharna on Coll and Callach Point on Mull, barely attains a breadth of seven miles. Geologically speaking, the two islands show but little variety for, except for the marble near Balephetrish on Tiree, they, like the Outer Isles,

are built of Lewisian Gneiss. However, as in the Outer Hebrides, diversity is added by the presence of a well-developed series of extensive sand dunes.

If due weight is attached to the proximity of Mull, one would expect that the Flora and Fauna of Coll, Tiree and Gunna would show close affinities with those of their larger neighbour. However, as one of us (J.W.H.H.) has already emphasised (Nature Vol. 147, page 134, February 1st, 1941), such expectations fail to harmonize with biogeographical facts. In a very extraordinary fashion, the Flora of Coll and Tiree corresponds much more closely with that of the Outer Islands lying more than thirty miles to the northwest.

Influenced, no doubt, by the nearness of Coll, Tiree and Gunna to Mull, Watson, in fixing the limits of his vice-counties, included all four in vice-county 103. Thus, all plant lists for v.-c. 103, by their inclusion of plants appertaining to two distinct phytogeographical areas, effectually mask the true relationships of the floras concerned. To remove this defect, Heslop Harrison (l. c.) has indicated the obvious remedy by transferring Coll, Tiree and Gunna to v.-c. 110, and differentiating the group as 110B.† This, in our opinion, is definitely preferable to allowing it to remain as 103B within the limits of 103; the latter procedure still perpetuates the inherent defect of linking two floras dissimilar in character and origin. Here we should like to make it quite clear that several botanists, whose opinions carry weight, have expressed their complete agreement with, and acceptance of, the proposed transfer. In future, therefore, we propose to treat Coll, Tiree and Gunna as forming v.-c. 110B.

In our previous publications dealing with Hebridean Floras, we have often had occasion to indicate how rich they were, and have given as tne reason the diverse geological formations the islands have presented. Here, without the latter obvious advantage, we can muster an unexpectedly large list of plants, including no fewer than 573 species, segregates and hybrids. This figure appears the more striking when the extremely exposed nature of the islands is taken into consideration.

We have now tne pleasing duty of tendering our usual thanks and acknowledgements. To no one can we be more grateful than Miss Sarah Kennedy and Mr. Malcolm Kennedy of Arinagour, Coll, who have uniformly displayed the greatest of kindness from the very inception of the work.

† Not 110A as was inadvertently stated in the "Nature" article.

Further, for help of a different type, we have to thank the authorities of the Royal Botanic Gardens at Edinburgh and Kew, and also Messrs. Ash, Pugsley, Nelmes and Watson who have so willingly given us assistance in their special groups. Lastly, we must express our gratitude to King's College Research Committee without whose financial aid our researches would have been quite impossible.

(The asterisk * indicates that the record is noteworthy as marking an extension of the known range or the rarity of the plant concerned.)

THE LIST OF PLANTS.

RANUNCULACEÆ.

Thalictrum dunense Dum. Sand Meadow Rue.
Very plentiful on dune and machair on all three islands.

***T. montanum.**
Forms referable to this occur in the northern parts of the Gallanach area and near Crossapol, on Coll.

***Ranunculus fluitans** Lam.
In a pool west of Crossapol Bay, Isle of Coll.

R. trichophyllus Chaix.
Not very common but found in shallow waters near Ballyhaugh, Lochan a Chuirn, Isle of Coll, Gunna, and in lochs between Scarinish and Balephetrish Hill, Tiree.

R. Drouetii F. Schultz.
Commoner than the preceding and widespread in the shallower lochs, streams and ditches on Coll and Tiree.

***R. heterophyllus** Weber.
Very rare; An Fhaodhail, Tiree.

***R. Baudotii** Godr.
Rather local in small lochs in the Caoles area and near Ben Hough, Isle of Coll and in Loch Bhasapoll, and An Fhaodhail, Isle of Tiree; form *marinus* Fr. occurs in the latter area, and also in rock pools on the islet, Soy Gunna, off Gunna.

***R. sceleratus** L. Celery leaved Crowfoot.
Very rare on the west end of Crossapol Bay, Coll.

R. Flammula L. Lesser Spearwort.
Very common on all three islands, as well as on Eilean Ornsay.

R. acris L. Buttercup.
Very common everywhere except on the moorlands; var. *Boraeanus* Jord. and *pumilus* Wahl. occur.

R. repens L. Creeping Crowfoot.
Common in ditches etc., on all the islands with Ornsay.

R. bulbosus L. Bulbous Buttercup.
Common enough on dune and machair on the three chief islands.

R. Ficaria L. Lesser Celandine.
More or less abundant on rock ledges and at the base of cliffs on Coll, Tiree and Gunna; the form developing fruit prevails.

Caltha palustris L. Marsh Marigold.
Common in every suitable place on all three islands and Ornsay; var. *Guerangerii* is very fine on Gunna.

NYMPHAEACEÆ.

Nymphaea alba L. White Waterlily.
Common in many of the larger lochs on Coll in moorland areas.

N. occidentalis Moss.
In several lochs north east of Arinagour, Coll.

PAPAVERACEÆ.

Papaver dubium L. Poppy.
Fields near Gallanach, Sorisdale, Cornaig etc., Coll, and near Kirkapoll, Tiree.

FUMARIACEÆ.

***Fumaria purpurea** Pugsl. Fumitory.
Rare, field north of Torastan, Coll.

F. Bastardii Bor.
Frequent on rye and oat fields, on the north west side of Coll, in the Gott Bay area of Tiree, casually on Gunna.

***F. Boraei** Jord.
Very rare, Arnabost, Coll.

CRUCIFERAE.

Nasturtium officinale L. Water-cress.
Quite common in streams and ditches, Coll, Tiree, Gunna; var. *siifolium* Reich. in a stream north west of Ben Hough and in the Gott Bay area, Tiree.

Arabis hirsuta Scop. Hairy Rock Cress.
Scattered on sand dunes, Gallanach, Totamore, Crossapol etc., Coll; also on similar points near Kilkenneth, on rocks on Ceann a'Mhara, and on bank sides between An Fhaodhail and Scarinish, Tiree.

Cardamine pratensis L. Cuckoo Flower.
Common in wet places, Coll, Tiree, Gunna.

C. hirsuta L. Hairy Bitter Cress.
Occasionally not rare in shady rocky places; throughout the islands.

C. flexuosa With.
Rock crevices and gorges near Meall na h'Iolaire, and down the coast to Loch Eatharna, Ben Feall, Coll and on Ben Hynish and Ceann a'Mhara, Tiree.

***Draba incana** L.
Rare on sand dunes at Gallanach, Cornaigbeg and Crossapol, Coll.

***Erophila verna** L.
Apparently not common; the var. *cabillonensis* (Jord.) O. E. Schultz on sand dunes on Tiree.

***E. Boerhaavii** (Van Hall) Dum.
As the var. *brachycarpa* Jord. on dunes near Arnabost.

Cochlearia officinalis L. Scurvy Grass.
Rather common on all the islands.

C. danica L.
Rocks etc. by the sea in the north west, Calgarry Point, etc., Coll; Gunna; between Salum and Miodar, Ceann a'Mhara, Rhudha Chraiginis, Tiree.

C. scotica Dr.
Rather rare and local on the coasts of all the islands.

***Sisymbrium Thalianum** Gay.
Rare; Dun an t'Sithein, Tiree.

S. officinale Scop.
Common near habitations, Sorisdale, Bousd, Arnabost, etc., Coll; Kirkapoll, Salum, Caoles etc., Tiree.

Erysimum orientale Mill.
A casual near the Pier, Gott Bay, Tiree.

***Subularia aquatica** L. Awlwort.
Very rare in Loch na Cloiche, on Coll.

Brassica Napus L.
Also casually on Tiree.

Sinapis arvensis L. Charlock.
Everywhere in fields on Coll and Tiree, but rarely plentiful.

Capsella Bursa-pastoris Medik. Shepherd's Purse.
Generally common on waste places near houses.

Cakile maritima Scop.
Somewhat local on shores; Gallanach, Feall Bay, Crossapol Bay, Coll; Traigh Bhagh and Balephuil Bay, Tiree.

Raphanus Raphanistrum L.
Common enough in fields on Coll and Tiree; var. *aureus* Wilm. occurs.

VIOLACEÆ.

Viola palustris L. Marsh Violet.
Fairly common and widespread on Coll, and Eilean Ornsay, but rather rare near Loch na Gile and west of Scarinish, Tiree.

***V. sylvestris** Lam. Wood Violet.
Rare between Loch Airidh Meall Bhreide and Caoles an Eilein, Coll; Balephetrish only, on Tiree.

V. Riviniana Reichb. Dog Violet.
Common enough on moorlands etc. on all the islands.

***V. canina** L. Dog Violet.
Not uncommon locally on machair and moorland; Clabhach, Grishipoll, south of Arinagour, Crossapol etc. Isle of Coll; Creagan Mora, Dun an t'Sithein, Tiree.

***V. canina** × **V. Riviniana.**
Near Clabhach, Isle of Coll.

***V. Lloydii** Jord.
Rare in rye fields, Arnabost to Sorisdale.

***V. agrestis** Jord.
Occasionally in fields, Coll and Tiree.

***V. obtusifolia** Jord.
Rare on waste ground between Scarinish and Baugh, Tiree.

V. Curtisii Forster.
Abundant on dune and machair from Sorisdale to Crossapol, Coll; eastern Gunna; Kilkenneth to Ruaig, Tiree.

POLYGALACEÆ.

Polygala vulgaris L. Milkwort.
Rather rare; Clabhach, Caoles, Isle of Coll; between Vaul and Salum, Tiree.

***P. dubia** Bellynk.
This proved not uncommon on moorland and dunes on Coll and Gunna, but we have no Tiree records.

P. serpyllacea Weihe.
Widely distributed and common on all three islands.

CARYOPHYLLACEÆ.

Silene maritima With. Sea Campion.
Local on sea cliffs and rocks, occasionally on dunes, on Coll, Tiree and Gunna.

Lychnis dioica L. Red Campion.
Abundant in one or two sea gorges on Ceann a' Mhara, and rarer on cliffs, An Cnap, Tiree.

L. Flos-cuculi L. Ragged Robin.
Common in damp places; all three isles.

***L. Githago** Scop. Corncockle.
Abundant in cornfields, Torastan, Gallanach, Cornaig, Coll.

Cerastium tetrandrum Curt.
Quite common on light soils, Coll, Tiree and Gunna.

C. viscosum L. Mouse-ear Chickweed.
Common in fields etc. on all three islands with Ornsay.

C. vulgatum L. Mouse-ear Chickweed.
Also common enough; all islands.

Stellaria media Vill. Chickweed.
Very common in various types of habitat; on all the isles.

S. Holostea L. Stitchwort.
Amongst rocks on the Arinagour side of Loch Eatharna, Coll.

S. uliginosa Murr. Bog Stitchwort.
Fairly well distributed in marshy places on Coll and Gunna; rather local on Tiree in the area between Gott Bay and The Reef.

Arenaria serpyllifolia L. Thyme-leaved Sandwort.
Quite common on dry banks, dunes etc. on all the islands.

Minuartia peploides (L.) Hiern. Sea Purslane.
Common on all the broad sandy bays on all the islands, and at times in salt marshes, as at Crossapol, Coll and The Reef, Tiree.

Sagina maritima G. Don. Sea Pearlwort.
Rocks between Cliad Bay and Grishipoll Bay, Coll, and also at Scarinish and between Vaul Bay and Balephetrish Bay, Tiree.

S. procumbens L. Procumbent Pearlwort.
Common on paths, bare ground etc. on all three islands and Ornsay, with the var. *spinosa* S. Gibs. on Tiree.

S. subulata Presl. Slender Pearlwort.
In bare and other places on moorlands; scattered thinly on Coll and Tiree.

S. nodosa Fenzl. Knotted Pearlwort.
Occasionally plentiful on damp slacks amongst sand dunes and on moorlands; Caoles to Calgary Point, Crossapol, Arileod, Cornaig, Sorisdale, etc., Coll; Gunna; The Reef, Ruaig etc. Tiree.

Spergula sativa Boenn. Corn Spurrey.
In cultivated fields, but never very common, on Coll and Tiree.

***Spergularia campestris** (All.) Aschers. Red Sandwort.
Very rare in one field east of Gallanach, Coll.

S. salina Presl. Sea Spurrey.
Not common; Lochs Eatharna and Breachacha, Coll; Urvaig, Tiree.

S. marginata Kittel. Sea Spurrey.
Rather commoner; Lochs Eatharna, Loch Gorton, Loch Breachacha, and Crossapol Bay, Coll; Urvaig, Tiree.

PORTULACEÆ.

Montia fontana L. Waterblinks.
Common in the form of var. *chondrosperma* Fenzl. in wet places on Coll and Gunna, but rare on Tiree near Loch Dubh and Kirkapoll.

HYPERICACEÆ.

Hypericum Androsaemum L. Tutsan.
Rare on cliffs in the Loch à Mhill Aird area, near Ornsay, and Meall nan Uan, Coll.

H. tetrapterum Fr. Square-stalked St. John's Wort.
Widely scattered in marshes etc.; Clabhach, Caoles, Totronald etc., Coll; Gunna; Ben Hynish, Tiree.

H. pulchrum L. Beautiful St. John's Wort.
Common in moorland places, rocks etc. on all three islands.

***H. elodes** L. Marsh St. John's Wort.
Plentiful in the Loch Urbhaig, Drum Fishaig, Crossapol areas etc., Coll; stream in the west of Gunna; Ben Hynish, Ceann a'Mhara, Salum, Tiree.

LINACEÆ.

***Radiola linoides** Roth. Allseed.
Rare in the Cliad district, Coll.

Linum catharticum L. Purging Flax.
Abundant on dry banks, dunes etc., on all three isles.

GERANIACEÆ.

***Geranium sanguineum** L. Bloody Cranesbill.
Rare on dunes at Sorisdale and Gallanach, inland cliffs near Torastan, plentiful on the Machair Mhor, and excessively abundant on the sand dunes at Crossapol, Coll; on Tiree apparently restricted to rock ledges facing south east on Ceann a' Mhara. White flowered forms were observed at Gallanach, Coll.

***G. pratense** L. Field Cranesbill.
This occurs, under somewhat natural conditions, as a semi-double form in several places in the Breachacha district of Coll. As it was also observed in one of the very few gardens at Arinagour, we asked whence it had been derived, and received the surprising answer that it had been brought in from wild stations along Loch Eatharna.

G. molle L. Dovesfoot Cranesbill.
In cultivated areas on Coll and Tiree, but also as a casual on Gunna.

G. pusillum Burm. fil.
Once in a field by the side of the Arnabost — Sorisdale road, Coll.

G. dissectum L. Jagged-leaved Cranesbill.
Rare in cultivated areas on Coll; on the rocks near An Cnap, and in a quarry at Heanish, Tiree.

G. Robertianum L. Herb Robert.
Rare; amongst rocks, Creag an Fhireoin, Coll.

Erodium cicutarium L'Hérit. Stork'sbill.
In all suitable places on dune, machair and cultivated ground on all three islands.

Oxalis Acetosella L. Wood Sorrel.
At first sight seemingly rare; actually quite common on rock ledges and amongst bracken at the base of cliffs from Loch Eatharna to Acha and in the Bousd-Meall nan Uan area, Coll.

LEGUMINOSAE.

Ulex europaeus L. Whin.
Near Arinagour and Breachacha on Coll, and near Scarinish, Tiree, probably introduced.

***Ononis repens** L. Rest-harrow.
A rather noteworthy find linking up with our Vatersay localities; near Acairseid an Dùin in the east of Tiree.

Medicago lupulina L. Black Medick.
Not well distributed, but common where it exists; Arinagour, Cliad, Coll; Scarinish, Tiree.

Trifolium pratense L. Red Clover.
Common in pastures etc. on Coll, Tiree and Gunna.

T. medium L.
Not very common at various places in the cultivated areas and on cliffs on Coll; rare on Ceann a'Mhara and Ben Hough, Tiree.

***T. Bocconi** Savi.
A party of our students, who collected on Coll in September 1939, discovered *Trifolium fragiferum* near Caoles and brought a large number of specimens home. Amongst these were three examples of the present species. A map showing the positions worked was drawn, and four of us spent a long time on the ground in 1940. However, despite our careful searches, no further specimens turned up; we learn that this uncertainty in appearances characterises the species everywhere.

T. repens L. White Clover.
Very common everywhere even on Ornsay; var. *rubescens* Ser. occurs fairly freely on Vaul Bay, Tiree, Gallanach, Coll and on Gunna.

***T. fragiferum** L. Strawberry Clover.
Plentiful at sea level in the salt marsh at Caoles, and elsewhere in that area, ascends to the moorland at Calgary Point and occurs on the moorlands north of Arileod; only seen on Coll.

T. procumbens L. Hop Trefoil.
Only near Kilbride, Coll.

T. dubium Sibth. Lesser Trefoil.
Common enough everywhere on all three islands.

Anthyllis Vulneraria L. Kidney Vetch.
Common on dunes and machair, occasionally on rocks; var. *maritima* Koch occurs; on all the islands.

Lotus corniculatus L. Bird's Foot Trefoil.
Common practically everywhere on all the islands including Ornsay; var *crassifolius* Pers. was found in the Balephetrish, An Cnap, Vaul area and elsewhere on Tiree, whilst var. *hirsutus* Rouy appeared on dunes, especially on sunny fixed slopes, on Coll, Tiree and Gunna.

L. uliginosus Schkuhr.
Very rare, near Arinagour, Coll.

Vicia Cracca L. Blue Vetch.
Sand dunes and machair generally, but also in fields; sometimes, especially in isolated localities, var. *argentea* Cosso and Germ. prevails; on every island.

V. sepium L. Bush Vetch.
Rocks, sand dunes and fields, but never really plentiful. Peculiar and really striking dwarf forms occur on the dunes at Crossapol, Coll whilst very strong forms, the reverse of these may be found on Ben Hynish and Ceann a'Mhara, Tiree.

V. sativa L. Tare.
In central Coll; a casual.

V. angustifolia L. Spring Vetch.
Widely spread on sand dunes and sometimes, as on the Crossapol dunes, very plentiful; on Coll only.

Lathyrus pratensis L. Meadow Vetchling.
Common as a rule in ditches, roadsides, etc. on all the islands.

L. montanus (L.) Bernh. Tuberous Bitter Vetch.
Rare; on rocks near Sorisdale and on the moor south of Arinagour, Coll.

ROSACEÆ.

Prunus spinosa L. Blackthorn.
Very rare; on a large rock not far from Arinagour, and in a gorge near Rudha Fasachd, Coll.

Filipendula Ulmaria (L.) Maxim. Meadowsweet.
Common in wet places on every island, even Ornsay.

Rubus idaeus L. Rasp.
Rare on rocks and cliffs ledges in the Loch Ronard, Loch à Mhill Aird area on Coll; An Cnap, Tiree.

*__R. sulcatus__ Vest. Blackberry.
Amongst rocks between Gallanach and Cornaig, Coll.

*__R. nitidus__ Whe. and Nees.
Roadside; Arinagour, Coll.

*__R. oxyanchus__ Sudre.
On a cliff edge, north of Gallanach, Coll.

R. dumnoniensis Bab.
One of the most plentiful brambles on Coll from Arinagour to the Round House.

R. polyanthemus Lindeb.
Also very common and widespread on Coll.

*__R. nemoralis__ P.J.M.
Cliffs near Kilbride and Arinabost, Coll.

*__R. Schlechtendalii__ var. **anglicus** Sudre.
On a cliff between Bousd and Cornaigbeg, Coll.

*__R. adenanthus__ Boul and Gill.
Not uncommon on the rocks between the Gallanach dunes and Sorisdale, Coll; a very southern form and one of the special forms linking the Coll-Tiree Flora with that of the Outer Isles.

R. mucronifer Sudre.
Not uncommon and scattered on Coll.

*__R. rotundifolius__ Bab. ex Blox.
On cliffs near Loch à Mhill Aird, Coll.

*__R. radula__ Whe.
Amongst rocks, An Cnap, Tiree.

*__R. adenolobus__ W. Wats.
On cliffs near Cornaigmore, Coll and near Creagan Mora, Tiree.

*__R. conjungens__ Bab.
On rocks, An Cnap, Tiree.

R. Balfourianus × **R. ulmifolius.**
On a cliff near Loch Cliad, Coll. This occurrence points to the fact that both *R. Balfourianus* and *R. ulmifolius* grow on Coll, but, up to the present, we have not detected them. This, however, cannot be surprising when one considers how sporadic the rock frequenting brambles are on Coll.

Fragaria vesca L. Strawberry.
Rare; cliff ledge, Bousd, Coll.

Potentilla sterilis Garcke. Barren Strawberry.
Very rare, on a rock ledge near Sorisdale, Coll.

P. erecta Hampe. Tormentil.
Plentiful on the moorlands; Coll, Tiree, Gunna.

*__P. reptans__ L. Cinquefoil.
Not before seen by us in the Hebrides; rare and local, on Coll near Crossapol, on Gunna, and on Tiree near Balephetrish, Balephuil and Sràid Ruadh.

P. Anserina L. Silverweed.
Very common on shingle, waste places etc., on all the islands with var. *concolor* Wallr. on Coll and Ornsay.

P. palustris Scop. Marsh Cinquefoil.
Also very common on all the islands in bogs etc.

Alchemilla arvensis Scop. Parsley Piert.
Very rare; near Baugh, Tiree.

***A. minor** Huds.
Var. *filicaulis* Buser is rare amongst rocks near Cornaig.

A. alpestris Schmidt.
Not common, Arnabost, Earth House, Cliad etc. on Coll; Ceann a'Mhara, Cornaig, on Tiree.

Rosa canina L. Agg. Dog-rose.

Lutetianae group.

(a) Var. **sphaerica** Dum. On rocks near Loch à Mhill Aird, and Loch Cliad, Coll; the form approaches very closely indeed to var. *lutetiana* Baker.

Transitoriæ group.

(b) Var. **rhynchocarpa** Rip. On ledges south of Gallanach Coll.

Dumales group.

(c) Var. **dumalis** Bechst: On ledges near Loch Cliad, Coll.

(d) Var. **Schlimperti** Hofm. Ledges near Loch Fada.

***R. dumetorum** Thuill. Agg.

Pubescentes group.

(a) Var. **semiglabra** Rip. A poorly characterised form which, if pubescence means anything, must be referred to this variety.

R. glaucophylla Winch. Agg.

Reuterianae group.

(a) Var. **Reuteri** (God.) H. Harr. On cliffs near Cornaig, on the west side of Loch Eatharna, south of Arinagour, near Ben Hogh, Coll; Ben Hough and ravine near Balephetrish, Tiree.

(1) f. **transiens** (Green). H.-Harr. Rocks near Eilean Ornsay, Coll.

(b) Var. **subcristata** (Baker) H.-Harr. Very well grown examples occur south-west of Arinagour, Coll, and near Balephetrish, Tiree.

(c) Var. **stephanocarpa** (Déségl. and Rip.) H.-Harr. Rock ledges near Cornaigbeg, Coll; the glandular vestiture on the lower side of the leaves is weak.

Subcaninae group.

(d) Var. **subcanina** Chr.

(1) f. **denticulata** R. Kell. Near Ceann à Bhàigh, Coll.

***R. coriifolia** Fr. Agg.

(a) Var. **Bakeri.** On rocks north-east of Gallanach, Coll; the form seems far from typical, but approaches nearest this variety. We have collected the same aberrant form on Colonsay.

***R. mollis** Sm. Agg.

(a) Var. **typica** W.-Dod. Rare on a stream side near Torastan, Coll.

R. Sherardi Dav. Agg.

(a) Var. **typica** W.-Dod. A little more abundant than most rose forms on Coll and Tiree; on many suitable ledges from Loch Cliad to Sorisdale, Coll; Ben Hough and Balephetrish, Tiree.

(1) f. **pseudomollis** E. G. Baker. In the same areas.

(b) Var. **Woodsiana** Groves. Scattered in the northwest of Coll on rocks, also on Eilean Ornsay.

(c) Var. **suberecta** Ley. Creagan Mora, Tiree.

R. spinosissima L. Burnet Rose.
(a) Var. **typica** W.-Dod. Very common on Coll, Loch Cliad, Gallanach, Bousd, Cornaig, Sorisdale etc.; also near Balephetrish, Tiree; the only rose on Gunna.
(b) Var. **pimpinellifolia** L. Scarce on the side of the Arnabost-Sorisdale road Coll; Ceann a'Mhara, Tiree.

***R. spinosissima** × **R. Sherardi** (=**R. Sabini** Wood).
One or two bushes on the side of the stream flowing from Toraston toward A Chroic.

Sorbus Aucuparia L. Mountain Ash.
Not uncommon on rock ledges, loch shores, islands in lochs on Coll.

***Crataegus monogyna** Jacq. Hawthorn.
Near Breachacha, Coll; this plant carried larvae of the moth *Acalla variegana* and hence may be a genuine native.

SAXIFRAGACEÆ.

***Saxifraga tridactylites** L. Rue-leaved Saxifrage.
Abundant on sand dunes from Arnabost Earth House to Machair Mhor, Coll; rare in dunes from Salum to Crossapol, Tiree.

***S. hypnoides** L. Mossy Saxifrage.
Rare on rocks near the Arnabost Earth House, but extremely abundant from the dunes north of that to Totamore, Isle of Coll.

***Chrysosplenium oppositifolium** L. Golden Saxifrage.
Very rare in a sea gorge near Eilean nam Faoileag, on N.E. Coll.

Parnassia palustris L. Grass of Parnassus.
Not at all rare behind the dunes on Coll from Sorisdale to Breachacha and Crossapol; rare on Tiree from Cornaig eastward.

CRASSULACEÆ.

Sedum roseum Scop. Roseroot.
Scattered at many places on sea cliffs on Coll, but only on Ceann a'Mhara, Tiree.

S. anglicum Huds. English Stonecrop.
Abundant on rocks inland and on the coast, on Tiree, Coll, Gunna and Ornsay.

S. acre L Biting Stonecrop.
Common enough on dunes and other sandy ground on the three main islands.

DROSERACEÆ.

Drosera rotundifolia L. Round-leaved Sundew.
Abundant on moorlands on Coll; more restricted on Tiree but not uncommon.

D. longifolia L. Long-leaved Sundew.
With the last named on both islands, but less common.

D. anglica Huds.
Not common in the Loch Ronard, Loch na Cloiche, Loch à Mhill Aird area on Coll.

HALORAGACEÆ.

Hippuris vulgaris L. Marestail.
Not uncommon in wet places on Tiree and Coll.

Myriophyllum spicatum L. Water Milfoil.
Common in very many lochs and even splash pools (as at Calgary Point) on Coll; in similar places on Tiree, where nearly every splash pool from Balephetrish to Vaul contains it; also found on Gunna.

M. alternifolium D.C.
Often in the same habitats as its ally, but not so common or widespread.

Callitriche stagnalis Scop. Starwort.
Common in pools, ditches and on mud on all three islands.

***C. intermedia** Hofm.
Abundant and of a colossal size in the stream near Acha, Coll; An Fhaodhail, stream north east of Ben Hough, Tiree.

***C. autumnalis** L.
Rare in Loch an Eilein, Tiree.

LYTHRACEÆ.

Peplis Portula L. Water Purslane.
Rather rare; two points in ditches west of Arnabost Earth House, Coll, and also in muddy places in fields between Kirkapoll and Balephetrish, Tiree.

Lythrum Salicaria L. Purple Loosestrife.
Very abundant between Ben Feall and Arileod, Acha, Uig, Caoles etc., Coll in damp fields, marshes etc.; also in similar places, An Fhaodhail, Kirkapoll, Loch Bhasapol, etc., Tiree.

ONAGRACEÆ.

Epilobium parviflorum Schreb. Downy Willow Herb.
Common in wet places of varying types; on all the islands.

E. montanum L. Smooth-leaved Willow Herb.
Scattered everywhere on Coll; Ben Hynish, Ceann a'Mhara, Ben Hough etc. Tiree; on Gunna also.

E. obscurum Schreb.
Thinly distributed in wet places on all the islands.

***E. adenocaulon** Hausk.
A remarkable find in a dried up loch in the Gallanach dunes; an American form which has colonised the south of England in recent years.

E. palustre L. Marsh Willow Herb.
Everywhere of sparse occurrence in Coll, Tiree and Gunna in wet places.

UMBELLIFERAE.

Hydrocotyle vulgaris L. Marsh Penny Wort.
In wet places plentiful on Coll, Tiree, Gunna and Ornsay.

***Eryngium maritimum** L. Sea Holly.
Not common; sea coast at Gallanach and Crossapol Bay on Coll; Tràigh Bagh and Vaul Bay, Tiree.

Conium maculatum L. Hemlock.
Near houses, Arinagour, Coll; Scarinish and Baugh, Tiree.

Apium nodiflorum Reichb. fil.
Sides of lochs, runners etc. scattered on Tiree.

A. inundatum Reich. fil.
Not uncommon both on Tiree and Coll in ditches, streams, lochs etc.

Sium erectum Huds.
Not very plentiful, streams between Gallanach and Cornaig, Coll, and in Loch an Eilean, stream near Sràid Ruadh, An Fhaodhail, Tiree.

Aegopodium Podagraria L. Goutweed.
Only near Arinagour, Coll.

Conopodium majus Loret.
Not common; Arinagour, and Arnabost, Coll; near Baugh, Tiree.

***Myrrhis odorata** Scop. Sweet Cicely.
Around old crofts, Sorisdale, Coll.

Anthriscus sylvestris Hoffm.
Common enough about houses etc. on Tiree and Coll; casually on Gunna.

Oenanthe Lachenalii C. Gmel.
Sparingly on Coll in wet grassy places near the sea as Hyne, Breachacha, Caoles an Eilein etc., common near Caoles; near the well on Gunna; Scarinish, An Fhaodhail, lochans near Urvaig and Salum, Tiree.

Oe. crocata L. Water Dropwort.
Very local on the seashore opposite Eilean Ornsay, Coll; along a stream just west of the Observatory, Hynish, Tiree.

Ligusticum scoticum L. Lovage.
On sea cliffs along the north west shore of Coll, not at all rare; on Gunna scarce; on Tiree restricted to Ceann a'Mhara and the cliffs between Vaul Bay and Balephetrish Bay.

Angelica sylvestris L. Angelica.
Common in wet places on all the islands.

Heracleum Sphondylium L. Cow Parnsip.
Common along ditches, path edges, rocks, etc.; on all the islands.

Daucus Carota L. Wild Carrot.
Plentiful in all kinds of dry places, on every island.

Caucalis Anthriscus Huds.
Rare near Arinagour, Coll and on Gunna.

ARALIACEÆ.

Hedera Helix L. Ivy.
Quite rare on cliffs near Loch Cliad opposite Arnabost, and near Loch à Mhill Aird, Coll.

CAPRIFOLIACEÆ.

Sambucus nigra L. Elder.
Near Arinagour and elsewhere on Coll; almost certainly introduced.

***Lonicera Periclymenum** L. Honeysuckle.
Not at all rare on rocks on Coll as var. *Clarki* H. Harr., also on Ornsay; on Tiree only on Ben Hynish and near Caoles.

RUBIACEÆ.

Galium verum L. Lady's Bedstraw.
Plentiful on dunes, machair, roadsides etc. on Coll, Tiree and Gunna.

G. saxatile L. Heath Bedstraw.
Common on heaths on all the islands including Ornsay.

G. palustre L. Marsh Bedstraw.
Common in wet places on all the islands.

G. uliginosum L. Bog Bedstraw.
In similar places to the preceding, but of much less frequent occurrence.

G. Aparine L. Cleavers.
Amongst rocks, on shingle etc., on all the islands.
Sherardia arvensis L. Field Madder.
Very local; roadside near Arinagour, Coll and near Baugh, Tiree.

VALERIANACEÆ.

Valeriana sambucifolia Mikan. Valerian.
Very rare; along the stream from Gorton to Acha, and also on that flowing into Loch Eatharna opposite Arnabost Farm.
Valerianella olitoria Poll. Lambs' Lettuce.
Fairly common on dunes on Coll, Tiree and Gunna with var. *lasiocarpa* Reichb. on Coll.

DIPSACEÆ.

Succisa pratensis Moench. Devil's Bit Scabious
Very plentiful on wet moorlands everywhere.

COMPOSITAE.

Solidago Virgaurea L. Golden Rod.
On inland rock ledges everywhere on Coll; on Tiree only on Ben Hough; also on Ornsay.
Bellis perennis L. Common Daisy.
Common everywhere on the islands.
Aster Tripolium L. Sea Aster.
Rare near Caoles and Breachacha, Coll; saltmarshes near Urvaig and Salum, An Fhaodhail, Acarsaid an Duin, Tiree.
Antennaria dioica Gaertn Everlasting.
Common on rocky moorlands on Coll, Tiree and Gunna; bright red flowered forms occur on Coll.
Gnaphalium uliginosum L. Cudweed.
Very rare; Breachacha area, Coll.
***Inula Helenium** L. Elecampane.
Here and there on Tiree; especially common near Middleton.
Achillea Millefolium L. Yarrow.
Very common everywhere with var. *villosa* Koch on Tiree.
A. Ptarmica L. Sneezewort.
Scattered in wet fields etc. on Coll, Tiree and Gunna; never really plentiful.
Chrysanthemum segetum L. Corn Marigold.
Too common in fields on Coll and Tiree.
C. Leucanthemum L. Ox Eye Daisy.
Rare and only found near Arinagour, Coll and Scarinish, Tiree.
Matricaria inodora L.
Well distributed both inland and on the coast, with the var. *maritima* L. on cliffs, shingle etc.; on Coll, Tiree, Gunna and Ornsay.
***M. suaveolens** Buchenau.
Near houses at Arinagour, Sorisdale, Uig etc. on Coll.
Tanacetum vulgare L. Tansy.
Always near human habitation, Arinagour, Cornaig etc. Coll; Baugh, Kirkapoll etc. Tiree.
Artemisia vulgaris L. Mugwort.
On field edges, in fields, waste places etc.; widespread both on Coll and Tiree.

Tussilago Farfara L. Coltsfoot.
Rather local, but sometimes very abundant on the sand dunes; rarer however at Gallanach, Crossapol etc., Coll; on Tiree on dunes between The Green and Cornaigmore; on the dunes on Gunna.

Petasites ovatus L. Butterbur.
Not uncommon locally between Arnabost and Cornaig along streamsides; also in similar places on streams near Hynish, Sràid Ruadh, Tiree.

Senecio vulgaris L. Common Groundsel.
Plentiful in fields, gardens, waste places on all the islands.

***S. sylvaticus** L.
Very rare on crags east of Machair Mhor, Coll.

S. Jacobaea L. Ragwort.
Very common on sand dunes, machair, waste ground, road sides etc. on every island.

S. aquaticus Hill. Marsh Ragwort.
Also plentiful but in wet places on all the islands, with Ornsay.

S. Jacobaea × **S. aquaticus.**
Sparingly, and somewhat variable, near Arinagour, Coll.

***Arctium nemorosum** Lej. Burdock.
Not common near Arinagour, Coll.

A. minus Bernh.
Less common than *Senecio Jacobaea*, but in much the same places.

***Carduus crispus** L.
On fixed sand dunes near Scarinish and on the opposite side of Gott Bay near Brock, Tiree. Odd plants occurred which looked like hybrids between this species and *Cn. lanceolatus* Willd.

Cnicus lanceolatus Willd. Spear Thistle.
In all kinds of waste places, fields etc.; well spread on all the islands.

C. palustris Willd. Marsh Thistle.
Well distributed in wet places on Coll and Tiree, but never common.

C. arvensis L. Creeping Thistle.
Abundant on sand dunes, fields etc. Var. *mitis* Koch occurs near Balephetrish, Tiree, and var. *setosus* Bess. occurs near the Round House, Coll.

Hypochoeris radicata L. Cat's-ear.
Common in many different types of habitat; all islands, including Ornsay.

Leontodon autumnale L. Hawkbit.
Plentiful on dunes, upper parts of salt marshes, fields etc.; both var. *pratense* Koch and *sordidum* Bab. occur on Tiree, but, as far as we could see, only the latter on Coll and Gunna.

L. hispidum L.
Rather rare; Crossapol to Ben Feall on Coll.

Taraxacum vulgare L. Dandelion.
Everywhere on all the islands.

T. laevigatum DC.
Common enough on dunes on all the islands.

T. paludosum Schlech.
In damp ground toward Calgary Point, Gallanach, Cornaig etc. on Coll; Salum and Urvaig, Tiree.

T. spectabile Dahlst.
Rock ledges on Ben Hough, An Cnap, Ceann a'Mhara, Tiree, also on Coll and Gunna.

***Centaurea obscura** Jord. Knapweed.
On Tiree and Coll; distribution not fully ascertained.

***C. nemoralis** Jord. Knapweed.
On Tiree, Coll and Gunna; distribution not completely determined. The aggregate species is common on the three islands.

Crepis capillaris Wallr. Smooth Hawk'sbeard.
Generally distributed, but preferring roadsides and similar places.

***Hieracium strictum** Fr. Hawkweed.
A form, which Mr. Pugsley refers to this species, grows in small numbers on many cliff ledges in the area between the rocks facing Arnabost Farm and Loch Fada, Isle of Coll.

H. Pilosella Tausch. Mouse-ear Hawkweed.
Scattered in dry places on Coll, Tiree and Gunna. (We have further forms which Mr. Pugsley regards as probably new; they await his study and description).

Sonchus oleraceus L. Sowthistle.
Cultivated ground; not uncommon on Coll and Tiree.

S. asper Hill.
Not very rare in similar places on the same islands.

S. arvensis L.
The least common of the three; found, however, on Coll, Tiree and Gunna.

CAMPANULACEÆ.

Lobelia Dortmanna L. Water Lobelia.
Plentiful in all the more peaty lochs on Coll, and in those around Loch na Gile and Loch Dubh, Tiree.

Campanula rotundifolia L. Hairbell.
Not rare on dry banks, rock ledges, dunes etc., on Coll where var. *hirta* Mert. & Koch. seems common enough; in addition var. *speciosa* More may be found on the Crossapol dunes; not uncommon on Gunna, but local, as on Ben Hough, Ceann a'Mhara, Balephetrish, Tiree.

VACCINIACEÆ.

Vaccinium Myrtillus L. Bilberry.
Often abundant on rocky places in the moorlands on Coll.

ERICACEÆ.

Arctostaphylos Uva-ursi Spreng. Bearberry.
Quite common on rocks in the Meall na h'Iolaire, Torastan, Loch Urbhaig triangle on Coll.

Calluna vulgaris Hull. Heather.
On moorlands everywhere, including Ornsay; very plentiful.

Erica Tetralix L. Cross-leaved Heath.
Also common in the same types of locality, but also passing into more marshy soil, also on Ornsay.

E. cinerea L. Fine-leaved Heath.
Perhaps a little less common on all three islands, with Ornsay.

Pyrola media Sw. Winter-green.
Very rare; one patch on the banks of Loch Airidh Meall Bhreide, Coll.

***P. minor** L. Lesser Winter-green.
Also very rare on the side of the Arinagour, Arnabost road, Coll.

PLUMBAGINACEÆ.

Armeria maritima Willd. Thrift.
Very common in salt marshes and on rocks; on all the isles with Ornsay.

PRIMULACEÆ.

Primula vulgaris L. Primrose.
Plentiful and well distributed on grassy banks, cliff ledges, and sand dunes on Coll, Gunna and Ornsay, but local on Ceann a'Mhara, Balephetrish Hill, between Urvaig and the Caoles road, Tiree.

***Lysimachia Nummularia** L. Creeping Jenny.
In marshy ground around Loch an Eilein, Tiree.

L. nemorum L. Moneywort.
Quite rare; amongst rocks near the coast near Arinagour, near Loch Urbhaig, and scattered elsewhere on cliff ledges, on Coll only.

Glaux maritima L. Sea Milkwort.
Common in saltmarshes and other places near the sea; every island with Ornsay.

Anagallis arvensis L. Scarlet Pimpernel.
Quite rare; fields near Gallanach, Coll and between Scarinish and Baugh, Tiree.

A. tenella Murr. Bog Pimpernel.
Everywhere common in wet places on all the islands.

Centunculus minimus L.
In a damp gateway near Cliad Farm, Coll.

Samolus Valerandi L. Brook Weed.
Plentiful on the sea shore near Eilean Ornsay, Coll; Gunna; more local on Tiree, An Fhaodhail, and lochs in the same area.

GENTIANACEÆ.

Erythraea Centaurium Pers. Centaury.
Common in dune slacks, dry banks etc., chiefly as the var. *capitata* Koch. on Coll, Tiree and Gunna.

***Gentiana baltica** Murb.
On dunes etc., rather rare; Coll and Gunna.

G. campestre L. Gentian.
On rocky knolls, fixed dunes etc., on Coll and Gunna.

Menyanthes trifoliata L. Bogbean.
Very common in many lochs, chiefly on the moors, in some of the smaller ones to the extent of choking them; Coll and Tiree.

BORAGINACEÆ.

Lycopsis arvensis L.
Common enough on arable land in Coll and Tiree.

***Mertensia maritima** Gray. Oyster Plant.
In one or two little bays on the north shore of Gunna.

Myosotis cespitosa Schultz. Forget-me-not.
Common in marshy places, Coll and Tiree.

M. repens G. & D. Don.
Only noted by us on Tiree but in similar places; Acarseid an Duin etc.

M. arvensis Hill.
Common in cultivated soils on Coll and Tiree.

M. versicolor Sm.
Plentiful in dry places; Coll and Tiree.

CONVOLVULACEÆ.

***Calystegia Soldanella** Br. Sea Convolvulus.
Plentiful on the seaward face of the dunes on Caoles Ban and near Gallanach, Coll.

SCROPHULARIACEÆ.

***Scrophularia nodosa** L. Figwort.
Very rare; ditch near Arinagour, Coll and on the rising ground east of Ruaig, Tiree.

***Digitalis purpurea** L. Foxglove.
Also very rare; on a rocky knoll near Arinagour, Coll and near Dun an t'Sithein, Tiree.

***Veronica polita** Fr.
In fields near Kirkapoll and as a garden weed near Baugh, Tiree.

V. agrestis L. Field Speedwell.
In a field between Cornaigmore and Gallanach, Coll.

V. arvensis L.
Quite common in waste places etc. Coll. Tiree and Gunna.

V. serpyllifolia L. Thyme-leaved Speedwell.
Not common in grassy places on Coll and Tiree; well distributed, however.

***V. Chamaedrys** L. Germander Speedwell.
Well distributed on Coll, especially on the sand dunes; very abundant on those at Crossapoll where the flowers are grey-blue and the whole plant hoary; on Tiree near Scarinish.

V. officinalis L. Common Speedwell.
Chiefly on rock ledges, but often enough amongst grass; widespread on Coll, very local on Tiree and Gunna.

***V. montana** L. Mountain Speedwell.
Rare at the base of rocks near Sorisdale, Coll.

V. scutellata L.
In wet places on the moorlands and near lochs on Coll and Tiree; var. *hirsuta* Weber occurs on Coll.

V. Anagallis-aquatica L. Water Speedwell.
Loch near Clabhach, Gallanach etc., Coll and common on loch edges, pools, ditches, An Fhaodhail, Loch Bhasapol etc., Tiree.

V. Beccabunga L. Brooklime.
Quite local; streams near Gallanach, Coll and near Sràid Ruadh and Scarinish, Tiree.

Euphrasia brevilipa Burnat & Gremli.
The form *subeglandulosa* Towns. occurs in the Salum-Urvaig area, Tiree, and near Loch Cliad, Coll.

E. brevipila × E. confusa.
In north-east Tiree.

E. nemorosa Pers.
As the var. *collina* Pugsl. at Cornaigmore, Gallanach and Acha, Isle of Coll and var. *sabulicola* Pugsl. at Gallanach; it is therefore well distributed.

E. confusa Pugsl.
Common on Coll as var. *albida* at Kilbride, Cornaig, Caoles, Cliad, Crossapoll and Calgary Point, also on Eilean Ornsay; on Tiree at Ruaig and Loch a'Phuill.

E. curta Fr.
The var. *glabrescens* Wettst. at Bousd, Coll.

***E. scotica** Wettst.
Loch Cliad, Coll.

E. micrantha Rchb.
Ballyhaugh, Gallanach, Cliad, Sorisdale and Bousd, Isle of Coll.

E. micrantha × E. confusa.
Sorisdale and Bousd, Coll.

***E. frigida** Pugsl.
A form, which Mr. Pugsley thinks possibly referable to this grows on rocks near Loch Cliad, Coll.

Bartsia Odontites Huds. Red Bartsia.
Very common in waste places, field edges etc., on Coll and Tiree.

Pedicularis palustris L. Marsh Lousewort.
Common in wet ground on the moorlands; all islands with Ornsay.

P. sylvatica L. Lousewort.
Also common in similar places.

***Rhinanthus major** Ehrh. Yellow Rattle.
Not common, but scattered on Coll and Tiree.

R. minor Ehrh.
Apparently common enough on both Tiree and Coll.

***R. stenophyllus** Schur.
This form is quite common and widespread in dune slacks, on machair, etc., on Coll and Tiree.

***R. monticola** Druce.
On rocky knolls in the Loch a'Mhill Aird area.

***Melampyrum pratense** L.
Scattered on damp heaths from Loch Airidh Meall Bhreide to Loch na Cloiche, Coll in the form of var. *ericetorum* D. Oliver.

LENTIBULARIACEÆ.

Utricularia vulgaris L. Bladderwort.
Ditches in Central Coll.

U. neglecta Lehm.
Here and there in lochs, pools and ditches; Coll and Tiree.

U. minor. Sm.
Common in lochs toward the west of Coll, especially in the Loch Fada area.

Pinguicula vulgaris L. Butterwort.
Common on damp moorlands on Coll, Tiree and Gunna; most of the plants around, and near, Loch Eatharna have rosy-purple flowers.

P. lusitanica L. Pale Butterwort.
Less common than its ally, but well distributed on moorlands on Coll.

LABIATAE.

***Mentha rotundifolia** Huds.
Near Arinagour, Coll.

***M. longifolia** Huds.
Cliad, Coll.

***M. piperita** L. Pepper-mint.
In wet ground west of Loch Bhasapoll, Tiree.

M. aquatica L. Water Mint.
Common on Coll in wet places, Cornaig, Gallanach, Clabhach, Acha, Breachacha, Caoles etc.; in the marsh near the well, Gunna; plentiful also at Cornaig, Ben Hough, Caoles etc., Tiree.

***Lycopus europaeus** L. Gipsywort.
Quite rare on Coll opposite Eilean Ornsay; common on Ornsay itself, and rare on Gunna.

Thymus ovatus Mill. Thyme.
On fixed dunes, banks etc. Crossapol, Gorton, Sorisdale on Coll, at Kilkenneth, Salum on Tiree; never common.

T. Serpyllum L.
As the type, and var. *silvicola* Wimm. & Grab., Crossapol, Machair Mhor, Gallanach etc. and var. *rigida* Wimm. & Grab. near Acha and Uig, Isle of Coll; common on Tiree and Gunna in the more typical forms.

***T. neglectus** Ronn.
Common and widely distributed on Coll, as at Sorisdale, Gallanach, Totamore, Crossapol, Gorton, Hyne etc.; also on Tiree in the north east and doubtless, elsewhere.

***T. britannicus** Ronn.
Well spread on Coll from Sorisdale, Ben Feall to Breachacha; also on Tiree.

Scutellaria galericulata L. Skullcap.
Very rare on Coll; in a sea gorge near Meall nan Uan.

S. minor Huds. Lesser Skullcap.
On moorlands on Coll from Loch Fada and Meall na h'Iolaire to Loch a'Mhill Aird and Loch Urbhaig, not rare; on Gunna, amongst heather, and on Tiree near Loch na Gile and Loch Dubh.

Prunella vulgaris L. Selfheal.
Abundant in all sorts of places on Coll and Tiree.

Stachys palustris L. Marsh Woundwort.
Not common; chiefly near Arinagour, Coll, but also near Cornaig, Gallanach etc.; on Tiree in the east.

S. sylvatica L. Woundwort.
At several points on Tiree; Dun an t'Sithein, Ben Hough, An Cnap, Ceann a'Mhara.

*× **S. ambigua** Sm. (= **S. palustris** × **S. sylvatica**).
Very common on Coll from Acha to Breachacha — a fact that seems very remarkable in the absence of *S. sylvatica;* the same peculiarity was noted on the Isle of Barra.

S. arvensis L. Field Woundwort.
In fields; Cornaigmore on Coll.

Galeopsis Tetrahit L. Hemp Nettle.
Also on arable land in the north west of Coll.

Lamium mollucellifolium Fr.
Scarce in the same area on Coll; at Baugh on Tiree.

***L. hybridum** Vill.
Also in similar places on both islands.

L. purpureum L. Red Dead-nettle.
Common as a weed in gardens etc. on Coll, and around Scarinish and Baugh, Tiree.

Teucrium Scorodonia L. Woodsage.
Not rare on rock ledges from Sorisdale to Creag an Fhireoin, also near Arinagour, on Coll; on Balephetrish Hill on Tiree, as well as on Gunna and Ornsay.

Ajuga reptans L. Bugle.
Very rare in two stations near Arinagour, Coll. In the first it grows in a meadow and is quite typical; in the second, it occurs near a large rocky knoll and is a very peculiar form, with lurid pink flowers. The latter looks a very distinct plant indeed.

***A. pyramidalis** L. Pyramidal Bugle.
Widespread on rock ledges on Coll; Grishipoll, Loch na Cloiche, Loch a'Mhill Aird area, sea gorge near Meall nan Uan etc. Var. *Helenae* H.-Harr. also occurs.

PLANTAGINACEÆ.

Plantago Coronopus L. Stag's Horn Plantain.
Very abundant on rocks etc. near the coast on all the islands; the var. *maritima* Gren. & Godr. on Ceann a'Mhara, Tiree.

P. maritima L. Sea Plantain.
Very common in salt marshes, on rocks etc. on the coast.

P. lanceolata L. Ribwort Plantain.
Plentiful in waste places, fields etc. on all the islands.

P. major L. Plantain.
Common in waste places etc.

Litorella uniflora Aschers.
Common in lochs; Loch Cliad, Loch an Duin, Loch Ronard etc., Coll; Loch Dubh and others in the same district, Tiree.

CHENOPODIACEÆ.

Chenopodium album L.
Common as a weed on all the islands, also on shingle on the shores.

Atriplex patula L.
Never common and apparently only collected on Tiree near Urvaig, on Gunna in the peculiar area between it and the islet Soy Gunna, and on Coll around Loch Breachacha.

A. glabriuscula Edmondst.
Fairly common on muddy and sandy shores on all the islands, including Eilean Ornsay.

A. laciniata L.
This species seems of limited distribution, for it was only observed on Coll on Feall Bay, and on Tiree at Vaul Bay, Urvaig, and rarely on Hough Bay.

Salicornia stricta Dum.
Never common, but occurring on Coll at Caoles and Breachacha, and on Tiree near Baugh and Urvaig.

***S. ramosissima** Woods.
Rare; in salt marshes at the west end of Crossapol Bay, Coll, and probably also on Tiree.

Suæda maritima Dum. Sea Blite.
Very local; on Coll in the Caoles salt marsh, Gallanach and Hyne, and on Tiree between Scarinish and Crossapol Pt., and at Urvaig and Salum.

Salsola Kali L. Prickly Saltwort.
Local in sandy bays; Crossapol Bay, Loch Breachacha, Caoles Ban etc., Coll; near the islet Soy Gunna, Gunna; Vaul and Salum Bays, Traigh Bagh, etc., Tiree. Var. *glabra* Deth. occurs.

POLYGONACEÆ.

Polygonum Convolvulus L.
Not uncommon as a weed on Coll and Tiree, as a casual on Gunna.

P. heterophyllum Lindman. Knotgrass.
Fields, roadsides, waste places on all the islands.

***P. aequale** Lindman.
In much the same localities, but less common.

P. Raii Bab.
Not common; Traigh Bagh and Vaul Bay, Tiree; Lochs Gorton and Breachacha, Coll.

P. Hydropiper L. Water-pepper.
Not uncommon along streams from Gallanach to Cornaigmore, Coll.

P. Persicaria L. Spotted Persicaria.
On cultivated ground, along streams etc.; fairly common in north west Coll, but rarer on Tiree and Gunna.

***P. Hydropiper** × **P. Persicaria.**
With the parents along the stream south west of A Chroic, Coll.

P. amphibium L.
Not very common on Coll, but occurring in the lochans between Calgary Point and Crossapol Bay, loch near Ben Hough, streams in the north west; scattered on damp ground on Tiree, but rare on Gunna.

Rumex obtusifolius L.
Common in all sorts of bare places, Coll, Tiree and Gunna.

R. crispus L.
On the same islands, as well as on Ornsay, but extending its habitats to rocks and shingle on the shores.

R. Acetosa L. Sorrel.
Very common on all the islands.

R. Acetosella L. Sheep's Sorrel.
Also common and widespread.

EUPHORBIACEÆ.

Euphorbia Helioscopia L. Sun Spurge,
Not very common on arable land, Gallanach, Cornaig etc., Coll; Kirkapoll, Tiree.

URTICACEÆ.

Urtica dioica L. Nettle.
Common near houses on Coll and Tiree; also found in the dunes on Gunna.

U. urens L.
In similar places, but much less plentiful; Coll, Tiree and Gunna.

MYRICACEÆ.

Myrica Gale L. Sweet Gale.
Plentiful on moorlands on Coll; more local in the Loch na Gile area, Tiree and on Gunna.

CUPULIFERAE.

***Betula pubescens** Ehrh. Birch.
Local on Coll; around Loch Fada, Loch Cliad, Loch Airidh Meall Bhreide and west side of Loch Eatharna.

***Alnus rotundifolia** Mill. Alder.
Odd examples near Arinagour, Coll.

***Corylus Avellana.** Hazel.
Sparingly on nearly every cliff ledge from Loch Fada to the eastern shores of Loch Cliad on Coll.

***Quercus Robur** L. Oak.
On rocky ground on Coll along the west shore of Loch Eatharna and also on rocks to the east of the Dairy Loch; clearly native in both cases when one considers its scrubby nature, its possession of the correct Cynipid galls and the plants like *Scilla non-scripta* associated with it.

***Q. sessiliflora** Salisb. Oak.
Also on rocky flats near the Dairy Loch, but much rarer.

SALICACEÆ.

Salix pentandra L. Bay-leaved Willow.
Near Arinagour and Breachacha, probably planted.

S. viminalis L. Osier.
Also near Arinagour and probably planted.

S. aurita L. Eared Sallow.
Abundant around lochs, on rocks, open moorlands, on islands in lochs etc. on Coll, and not rare on Gunna and Ornsay; on Tiree only on rock ledges on Ceann a' Mhara and Ben Hough.

***S. aurita × S. atrocinerea.**
Very rare on an island in Loch Ghillecaluim on Coll.

S. aurita × S. repens.
Odd plants in the Meall nam Muc district.

S. aurita × S. viminalis.
In Central Coll.

***S. atrocinerea** Brot.
Very rare, indeed, but exceptionally fine on islands in Loch Ghillecaluim, Coll.

S. repens L. Dwarf Sallow.
Widespread on moorlands etc. on all the islands, including Ornsay.

***S. Andersoniana** Sm. Dusky Sallow.
Also on an island in Loch Ghillecaluim, Coll.

Populus tremula L. Aspen.
On very many rock ledges from Ben Hough to Sorisdale; quite well-grown trees exist in gorges on the coast between Arinagour and Eilean Ornsay; restricted to Coll.

EMPETRACEÆ.

Empetrum nigrum L. Black Crowberry.
Common and well distributed on rocky moorlands on Coll, Gunna and Ornsay.

ORCHIDACEÆ.

***Malaxis paludosa** Sw. Bog Orchid.
Plentiful amongst moss at the Cliad Farm end of Loch Cliad, and near Loch Ronard.

Listera cordata Br. Small Twayblade.
On moorlands on Coll under heather and bracken, Loch a' Mhill Aird.

L. ovata Br. Twayblade.
Not common on Coll; Cornaigbeg, Sorisdale, Gallanach areas.

***Spiranthes stricta** Nelson (=**S. Romanzoffiana** p.p.) Irish Ladies' Tresses.
This remarkable discovery was made by Mr. J. Heslop Harrison with a party of students in August 1939, and confirmed by us in August 1940. Although the original plants were noted on the northern shores of Loch Cliad, we collected it very close to Arinagour and far away to the north east near Bousd and Sorisdale. Further, we have information that it exists near Arileod in the south west. Thus the plant may be expected anywhere on damp moorlands on Coll.
The species exists in two forms on Coll, one with a massive spike and the other with a lighter and more conical head.

***Anacamptis pyramidalis** Rich. Pyramidal Orchid.
Far from rare on the Cliad Bay and Gallanach dunes, and also on those around Crossapol Bay, Coll; discovered by our students on the Gunna dunes.

Orchis mascula L. Early Purple Orchid.
Plentiful on Coll on rock ledges, alongside walls around fields, etc.; in similar places on Gunna and on Ben Hough, and near Salum, Tiree.

O. latifolia L. (**incarnata** auct.)
Chiefly in dune slacks and occasionally on moorlands, but common from one end of Coll to the other, not rare on Gunna and also plentiful on Tiree. Var. *coccinea* Pugs. is sometimes very striking.

***O. purpurella** Stph.
Very rare in Central Coll, only two plants being seen there, but abundant near Sorisdale in the north east and at Uig, Acha, and other points in the south west; on Tiree, common on the western slopes of Ben Hynish, north of Barrapol, and locally from Hough Bay to Cornaigmore; Gunna, rare near the well.

***O. latifolia** × **O. purpurella.**
In a mixed colony of these two species on the south side of Sorisdale Bay.

***O. majalis** Rchb. subsp. **occidentalis** Pugsl.
In a little marshy hollow near Sorisdale, Coll and near Carachan, Tiree.

O. ericetorum Linton. Spotted Orchid.
Common and widely spread on moorlands on Coll, Tiree and Gunna.

O. ericetorum × **O. latifolia.**
Near Breachacha, Coll and Scarinish Moor, Tiree.

O. ericetorum × **O. purpurella.**
Near Cornaigbeg, Coll.

***O. maculata** L. var. **hebridensis** (Wilm.) H.-Harrison.
Everywhere on Coll, Tiree and Gunna, although not so common as its ally *O. ericetorum;* very large forms were collected on Coll.

***O. maculata** var. **hebridensis** (Wilm.) H.-Harr. × **O. latifolia** L.
In a marsh between Meall na h'Iolaire and Sorisdale, Coll.

***O. maculata** var. **hebridensis** × **O. purpurella.**
In a little marsh between Sorisdale and Bousd, Isle of Coll.

***O. maculata** var. **hebridensis** × **O. ericetorum.**
The marsh and moorland near Acha Mill, Coll.

***O. maculata** var. **hebridensis** × **Gymnadenia conopsea.**
Only on Ceann Fasachd, Coll.

***Gymnadenia conopsea** Br. Fragrant Orchid.
Locally not rare; Crossapol, Breachacha, Gallanach, Cornaig, on Coll only.

***Leucorchis albida** Mey.
Only near Crossapol, Coll.

Coeloglossum viride Hartm. Frog Orchid.
Dunes at Ballyhaugh, Crossapol, and on grassy banks near Acha Mill and on Ceann Faschd, on Coll.

***C. viride** × **G. conopsea** (= × **Gymnaglossum Jacksonii** Rolfe).
This very remarkable hybrid, only known previously from Hampshire and Shropshire, was collected on Ceann Fasachd, Coll.

Platanthera bifolia Reich. fil. Butterfly Orchid.
Quite rare on Coll; Cornaig and Crossapol.

IRIDACEÆ.

Iris Pseudacorus L. Iris.
Very common throughout Coll, Tiree, Gunna and Ornsay.

***Sisyrinchium angustifolium** Mill. Blue-eyed Grass.
Another member of the Irish-American element discovered on Coll; only grows on damp slopes in the south east angle of Loch Cliad.

LILIACEÆ.

Allium vineale L.
On a rock ledge west of Sorisdale, Coll.

A. ursinum L. Garlic.
Along the west shores of Loch Eatharna, Coll, amongst rocks; rare except at one point; in sea gorges on ledges on Ceann a'Mhara, Tiree.

***Scilla verna** Huds. Vernal Squill.
Local, but often abundant where it occurs; on Coll on rocks from Crossapol to Calgary Point; on Gunna in the west, and often filling rock crevices, and on Tiree from the Observatory to Ceann a'Mhara.

S. non-scripta Hoffm. & Link. Bluebell.
Common on very many rock ledges, rocky knolls and in pastures on Coll, also amongst bracken clad rocks on Eilean Ornsay and in rocky gorges etc., Ceann a'Mhara, Tiree.

Narthecium ossifragum Huds. Bog Asphodel.
Common on moorlands on Coll, Tiree, Gunna and Ornsay.

JUNCACEÆ.

Juncus bufonius L. Toadrush.
Abundant in wet places on Coll, Tiree and Gunna.

J. squarrosus L. Heath Rush.
Common enough on heaths on Coll, Tiree and Gunna.

J. Gerardi Lois.
In salt marshes and mud flats, not rare; Loch Eatharna, Hyne, Gorton, Breachacha, Caoles, Gallanach etc., Coll; An Fhaodhail, Heanish, Urvaig, Salum, etc., Tiree; also on Gunna and Ornsay.

***J. balticus** Willd.
Common; An Fhaodhail and The Reef generally, Tiree only.

J. effusus L. Soft Rush.
Rather sparingly on Coll and Tiree.

J. conglomeratus L. Common Rush.
Common on all the islands, with Ornsay.

***J. maritimus** Lam. Sea Rush.
Common along Loch Eatharna, Coll only.

J. bulbosus L. Lesser Jointed Rush.
Scattered on Coll, Tiree and Gunna and not rare.

J. articulatus L.
Common on the same islands.

J. sylvaticus Reich.
In bogs on Coll and, as far as we could determine, not common.

Luzula pilosa Willd.
Not common on rock ledges near Loch Cliad, island in Loch Ghillecaluim, near Loch Eatharna and other sheltered places on Coll.

L. sylvatica Gaud. Great Hairy Woodrush.
Local, but occasionally abundant on rocks; Druim Fishaig, Loch Cliad, Ceann Fasachd etc., Coll.

L. campestris L. Field Woodrush.
Common everywhere in grassy places on Coll, Tiree and Gunna.

L. multiflora DC.
On moorlands on all the islands with Ornsay; var. *congesta* Lej. occurs likewise.

TYPHACEÆ.

Sparganium ramosum Curt. Bur-reed.
Here and there; on Coll near Cornaig, Gallanach etc., on Tiree near Sràid Ruadh etc.

***S. neglectum** Beeby.
On Coll and Tiree in many lochs and peaty pools.

S. simplex Huds.
A little more common than the preceding and equally widely spread.

LEMNACEÆ.

Lemna minor L. Lesser Duckweed.
Local on Tiree and Coll; west of Loch Bhasapoll on the former island, and in the district between Cornaig and Clabhach on Coll.

ALISMACEÆ.

Alisma ranunculoides L.
Rare on Coll in same places as the preceding species and also west of Caoles; on Tiree widely spread and common in many lochs, ditches etc.

NAIADACEÆ.

Triglochin palustre L. Arrow-grass.
Common on marshy ground on all the islands.

T. maritimum L. Sea Arrow-grass.
Common in salt marshes and elsewhere near the sea on all the islands.

Potamogeton polygonifolius Pourr.
Common and variable, on marshy ground and in lochs on Coll, Tiree and Gunna.

***P. coloratus** Hornem.
Rare in Lochan a Chùirn, south of Caoles, Coll and near Balephetrish Hill, Tiree.

P. gramineus L.
Well distributed on Tiree, but only in the shallower non-peaty lochs on Coll; Loch an Eilein, Loch Bhasapoll, Loch a'Phuill, on Tiree; in Lochan a Chuirn, and a loch near Ballyhaugh, Coll.

***P. nitens** (=**P. gramineus** × **P. perfoliatus**).
Rare in the loch near Ballyhaugh, Coll and in Loch an Eilein, Tiree.

P. perfoliatus L.
Not common; Loch Cliad, Coll, and Loch Bhasapoll and Loch an Eilein, Tiree.

***P. Berchtoldii** Fieb.
Only collected on Coll; in the loch near Ballyhaugh, lochan near Loch a'Mhill Aird, and Lochan a Chuirn.

P. pectinatus L.
In Loch Bhasapoll, Tiree.

*× **P. suecicus** Richt. (= **P. pectinatus** × **P. filiformis**).
Found only in a small stream running from Loch a'Phuill to Balephuil Bay, Tiree.

***P. filiformis** Pers.
Rare in a splashpool on Calgary Point, Coll; An Fhaodhail, Loch Bhasapoll, Loch a'Phuill, Loch an Eilein, streamlet near Corraigmore, Loch Odhrasgair and in many splashpools from Rudh'an Fhaing to An Cnap, Tiree.

Ruppia rostellata Koch.
Rare in streams near Gallanach, Breachacha and Caoles, Coll.

Zannichellia palustris L.
Stream near Gallanach, Coll.

Zostera marina L.
Washed ashore at several points on Coll and Tiree.

***Z. nana** Roth.
Also washed ashore on Crossapol Bay, Coll.

ERIOCAULACEÆ.

***Eriocaulon septangulare** With. Pipewort.
Another representative of the American element in the Coll Flora; excessively abundant in Loch a'Mhill Aird, and more or less plentiful in about a dozen lochs in the same area including Loch Ronard, Loch na Cloiche, Loch a Crotha etc. Some of these are quite large expanses of water, whilst others are mere pools; some drain eastward, but most run to the west, and so on.

CYPERACEÆ.

Eleocharis palustris Roem. & Schult.
Very common, indeed, everywhere in watery places.

E. uniglumis Schultes.
Not so common as the preceding, but on Coll from Sorisdale to Ballyhaugh, Crossapol etc.; on Tiree along the N.W. coast, An Fhaodhail and on Gunna.

E. multicaulis Sm.
Scattered on the moorlands on Coll and Tiree.

Scirpus pauciflorus Lightf.
Quite common on Coll, Tiree and Gunna.

S. caespitosus L.
Well distributed on Coll and Ornsay, but only in the Dun an t'Sithein area, Tiree.

S. fluitans L.
Common in ditches, pools and runners on Coll, Tiree and Gunna.

***S. filiformis** Savi.
Not rare in damp places near Cliad and other points in the west of Coll.

S. setaceus L.
In barish, damp places on Coll and Tiree, but never common.

S. lacustris L.
In Loch Cliad and Loch an Duin, Coll, rare.

S. Tabernaemontani Gmel.
Also in Loch Cliad and in one of the streams in the Gallanach area, Coll; Loch Bhasapoll and in a splashpool near An Cnap, Tiree.

S. maritimus L. Sea Clubrush.
Very local; saltmarsh near Caoles, Breachacha and Calgary Point, Coll, and An Fhaodhail and Urvaig, Tiree.

S. rufus Schrad.
Local; Crossapol and Calgarry Point, Coll; An Fhaodhail, The Reef and Urvaig, Tiree.

Eriophorum vaginatum L. Cotton Grass.
Well distributed on Coll, Tiree and Gunna, but not so common as the following; nevertheless, found on Ornsay.

E. angustifolium Roth. Cotton Grass.
Common on wet moorlands; Coll, Tiree, Gunna and also on Eilean Mhor, off the N.E. corner of Coll.

Rynchospora alba Vahl. White Beaked Rush.
Common on the Coll moorlands, although somewhat local.

Schoenus nigricans L.
Abundant in moorland localities; Coll, Tiree and Gunna.

***Cladium Mariscus** Br.
Not uncommon in Loch Cliad, Loch an Duin, Loch na Cloiche and other lochs and lochans in the same area, Loch Ghillecaluim; limited to Coll.

Carex dioica L.
Not common; moorlands on Coll and Tiree.

C. pulicaris L. Flea Sedge.
Common on Coll, Tiree and Gunna.

***C. disticha** Huds.
Locally common in ditches and on marshy ground, Cornaigmore, Tiree.

C. arenaria L. Sand Sedge.
Abundant on dunes and sandy soil; Coll, Tiree and Gunna.

***C. diandra** Schrank.
Not rare around a small lochan near the Dun Beag, Moidar, Tiree.

***C. paniculata** L.
Plentiful in a marsh at the south end of Loch Bhasapoll, Tiree.

***C. paradoxa** Willd.
Rare on Gunna, and only recorded once previously from a Scottish locality. This was in Peebles.

C. echinata Murr. Star Sedge.
Not rare and well distributed on moorlands on Coll, Tiree and Gunna.

C. Otrubae Pod. (= **vulpina** auct.) Fox Sedge.
Local and chiefly on streams and about splashpools near the shore; Gallanach, Calgary Point etc., Coll, and on Tiree from Balephetrish Bay to Vaul and on The Reef.

***C. canescens** Lightf.
Rare on rocks near Loch a'Mhill Aird, Coll.

C. leporina L. Hare's Foot Sedge.
Shores of Loch Eatharna etc. Coll and well distributed on Tiree; never very plentiful.

***C. Hudsonii** Ar. Benn.
Rare on the shores of Loch Bhasapoll, Tiree.

***C. rigida** Good.
On rocky ridges near Loch Ronard, Loch na Cloiche etc.; quite rare.

C. Goodenowii Gay.
Common enough in wet heathy places, Coll, Tiree and Gunna.

C. diversicolor Crantz.
Well distributed, chiefly near the sea, Coll, Tiree and Gunna

***C. limosa** L.
Very rare and local; bog near Loch a'Mhill Aird, Coll.

C. pilulifera L.
In wet places on Coll and Gunna and not really rare; not plentiful on Tiree.

***C. caryophyllea** Latour. Carnation Sedge.
Thinly spread over Coll, but rare on a grassy slope on Ceann a'Mhara, Tiree.

C. panicea L.
Occasionally common on all three islands, but local.

***C. sylvatica** Huds. Wood Sedge.
On a grassy bank side near the cist between Miodar and Caoles, Tiree.

***C. helodes** Link.
In the Urvaig-Miodar district, Tiree.

C. binervis L.
Not very common amongst heather on Coll, Tiree and Gunna.

C. fulva Host.
Moorlands on Coll and Tiree.

C. fulva × C. lepidocarpa.
With the parents on Coll and Tiree.

C. distans L.
Rather limited in its distribution; Calgary Point, Coll, Balephetrish Bay to An Cnap, Tiree and Gunna.

C. extensa Good.
Not widespread; Crossapol, Calgary Pt., Gallanach, Breachacha, etc. Coll; An Fhaodhail, Tiree and Gunna.

C. flava L.
Fairly common, Tiree, Coll and Gunna; also var. *minor* Towns.

C. lepidocarpa Tausch.
Occasionally on moorlands, Coll and Tiree.

C. Oederi Ritz.
Very rare on Coll; nevertheless, the var. *œdocarpa* And. is widespread on Coll, Tiree and Gunna.

C. lasiocarpa Ehr.
Abundant on the shores of lochs in the Loch a'Mhill Aird area, Coll.

C. hirta L. Hairy Sedge.
Not uncommon on the banks on roadsides in the Scarinish, Balephetrish and other districts on Tiree.

C. rostrata Stokes.
Common in ditches, streams, shallow lochs on Coll and Tiree.

***C. riparia** Curt.
Collected by our students in the Acha area, Coll.

GRAMINEÆ.

***Phalaris arundinacea** L. Ribbon Grass.
Very local on Coll, but plentiful on the banks of a stream, running into Cliad Bay.

Anthoxanthum odoratum L. Sweet Vernal Grass.
Everywhere common on Coll, Tiree, Gunna and Ornsay.

Alopecurus geniculatus L.
Common in ditches and wet places on Coll, Tiree and Gunna.

A. pratensis L. Foxtail.
Very rare on the roadside near Arinagour, Coll

Phleum pratense L. Timothy.
Near Arinagour and Caoles, Coll.
Agrostis canina L.
Plentiful and well distributed on Coll and Tiree.
A. alba L.
Very common on all the islands.
A. tenuis Sibth.
Common on all three islands with var. *pumila* L.
Ammophila arenaria Link. Marram Grass.
Abundant on sand dunes everywhere.
Aira caryophyllea L.
Very rare, on a bank side near Arinagour, Coll, and in a small quarry near Salum, Tiree.
A. praecox L.
On bare paths, roadsides, wall tops etc.; common everywhere.
Deschampsia caespitosa Beauv. Tufted Hair Grass.
Not very common; Balephetrish Hill, Ben Hough on Tiree, and Druim Fishaig and Gallanach, Coll.
***D. setacea** Richter.
On the margins of many lochs in the north eastern half of Coll and in a long narrow pool near Loch Dubh, Tiree.
D. flexuosa Trin. Wavy Hair Grass.
Not plentiful on Coll; only in clefts in the rocks running down to the sea near Eilean Ornsay.
Holcus mollis L.
Uncommon in sheltered places as Creag an Fhireoin, Coll; also on Tiree.
H. lanatus L.
Very common on all the islands, including Ornsay.
***Trisetum flavescens** Beauv.
Plentiful on the road side near Heylipoll on Tiree.
Avena pubescens Huds.
Not uncommon on grassy slopes and cliff ledges near the sea on Tiree, Coll, Gunna and Ornsay.
Arrhenatherum tuberosum Gilib.
Not rare,in waste places on Tiree and Coll.
Sieglingia decumbens Bernh.
Common in moorlands situations on Coll and Tiree.
Phragmitis communis Trin. Common Reed.
Common in lochs and marshy places on Coll, Tiree and Gunna.
Cynosurus cristatus L.
Very common on Coll, Tiree and Gunna; viviparous specimens were collected near the Lodge, Arinagour, Coll.
Koeleria gracilis Pers.
Not rare on grassy places by the sea on Coll, Tiree and Gunna.
Molinia caerulea Moench.
Generally distributed on moorlands on Coll, Gunna and Ornsay; much rarer on Tiree.
Catabrosa aquatica Beauv.
Abundant on sandy shores where streamlets spread out as they enter the sea; all three islands with Ornsay.
Dactylis glomerata L. Cocksfoot.
Very rare; on the roadside near Arinagour, Coll and at Gott and near the marble quarry, Balephetrish, Tiree.
***Briza media** L. Quaking Grass.
Very rare on Gott Bay, near the Manse, Tiree.
Poa annua L. Annual Meadow Grass.
Everywhere very common.

P. pratensis L.
Common on Coll, Tiree and Gunna with the var. *subcærulea* Sm. amongst the Marram Grass on the Dunes.

***P. palustris** L.
Local and always amongst Irises; Arnabost, Gallanach etc., on Coll, and very common between Urvaig and Salum, Tiree.

P. trivialis L.
Generally distributed on Coll, Tiree and Gunna.

Glyceria fluitans Br.
Common in wet places on Coll, Tiree and Gunna.

***G. maritima** Mert. & Koch.
In salt marshes; Loch Eatharna, Crossapol, Gallanach etc., Coll; Urvaig and Salum, Tiree; the islet Soy Gunna, off Gunna and Eilean Ornsay.

Festuca rottboellioides Kunth.
On sand dunes and similar places; Crossapol, Hough Bay, Breachacha, etc., Coll; Balemartine, Tràigh Mhor, the Observatory, Balephetrish Bay, Tiree and Gunna.

***F. bromoides** L.
Very rare in a ditch by the roadside between Acha and Uig, Coll.

F. ovina L. Sheep's Fescue.
Var. *genuina* Gren. & Godr., in the unproliferated form, was only collected from Gallanach and Clabhach on Coll, where it was not common. Var. *genuina* in the viviparous guise was common on all the islands; on the other hand proliferated var. *hispidula* (Hack.) Richt. was only noted on a knoll near Scarinish, Tiree.
In terms of Turesson's apomicts, we found apom. *norvegica* Turess. and apom. *færænsis* Turess.

***Festuca glauca** Lam.
This grass was extremely abundant on Coll in the area around Lochs Cinneachan and Anlaimh, as well as in flats amongst rocks in the district between Gallanach and Cornaigbeg. It, however, only occurred where dune conditions gave place to moorland. The form collected was always the apomictic plant, var. or apom. *hebridensis* H.-Harrison.

F. rubra L. Red Fescue.
The var. *vulgaris* Gaud. appears common enough on Coll, Tiree and Gunna. Var. *glaucescens* (Hegets. & Heer) Richt. is not rare on rock ledges on the same islands whilst var. *arenaria* Ost. seems not uncommon on the margins of sand

F. pratensis Huds.
In a meadow near Arinagour, Coll and in a dampish field, Gott, Tiree.

Bromus hordeaceus L. Common Brome Grass.
Very common as a weed of arable land and in waste places on Coll and Tiree.

Brachypodium sylvaticum Roem. & Schult.
On cliff ledges on Coll and Tiree; local, but fairly widespread, on the former; only on Ben Hough, Ceann a'Mhara and Ben Hynish, on Tiree.

Lolium perenne L. Perennial Rye Grass.
Of general occurrence on Coll and Tiree, but never plentiful except where planted.

L. multiflorum L. Italian Rye Grass.
As an escape from cultivation on Coll and Tiree.

Agropyron repens Beauv.
Not uncommon in waste places and on shingle on Coll, Tiree and Gunna.

A. junceum Beauv.
Common on sand dunes on Coll, Tiree and Gunna.
Nardus stricta L.
Quite common everywhere in moorland localities on Coll, Gunna and Ornsay, but slightly more restricted in its range on Tiree.

CONIFERAE.

Juniperus communis L. Juniper.
Very rare in the centre of Coll on the Druim Fishaig ridges.
J. sibirica Burgsdorf. Dwarf Juniper.
Common enough on rocks on Coll, but also occurring on Ornsay.

FILICES.

Hymenophyllum peltatum Desv. Filmy Fern.
Very rare and local; sheltered cliffs near the coast, Meall nan Uan and in a gully at Grishipoll, Coll.
Pteris aquilina L. Bracken.
Abundant throughout the islands, Ornsay included.
Blechnum Spicant With. Hard Fern.
On rocks and cliffs on the moorland areas of Coll, Gunna and Ornsay; on Tiree only on such places as Ben Hynish, Ceann a'Mhara.
Asplenium Adiantum-nigrum L.
Not uncommon in rock crevices; Bousd, Druim Fishaig, Torastan etc., Coll; only on Balephetrish Hill and Ceann a'Mhara, Tiree.
A. marinum L. Sea Spleenwort.
Local on sea cliffs on all the islands; Grishipoll Point, Ben Feall, Meall nan Uan etc. on Coll; Ceann a'Mhara, An Cnap on Tiree, and also on Gunna.
A. Trichomanes L.
Very local and rare; Ben Feall and Grishipoll, Coll and An Cnap, Tiree.
A. Ruta-muraria L. Wall-rue.
Rare on the cliffs south of Crossapol and on Ben Feall, Coll.
Athyrium Filix-foemina Roth. Lady Fern.
Generally distributed in sheltered places on all the islands.
***Phyllitis Scolopendrium** Newm. Hart's Tongue Fern.
Very rare; rock crevices on Creag an Fhireoin and Ben Feall, in a sea gorge near Meall nan Uan on Coll; on Ceann a'Mhara, Tiree.
Lastrea Filix-mas Presl. Male Fern.
Not uncommon on all the islands in sheltered places.
L. spinulosa Presl.
Very rare; on the same island in Loch Ghille-caluim, Coll, as provided the rarer Salices.
L. aristata Rendle & Britten.
Common enough in Coll, Gunna and Ornsay, but local in the west of Tiree.
L. aemula Brackenridge.
Common along the Coll coast from Loch Urbhaig to Ceann Fasachd on rocks; especially plentiful just behind Arinagour.
Polypodium vulgare L. Common Polypody.
Local on grassy ledges and cliffs on all the islands.
***Phegopteris polypodioides** Fee.
Only in a ravine near Eilean nam Faoileag, Coll.

Osmunda regalis L. Royal Fern.
Not rare on Coll; along stream and loch edges and on islands in lochs. On those north east of Loch Eatharna it grows very luxuriantly and is abundant.

***Ophioglossum vulgatum** L. Adder's Tongue Fern.
Grassy places; opposite Eilean Ornsay, west of Caoles on Coll; on The Reef, Tiree and on the south of Gunna.

Botrychium Lunaria L. Moonwort.
Well distributed on Tiree and Coll on fixed dunes and grassy knolls; less common than Ophioglossum.

EQUISETACEÆ.

Equisetum arvense L. Common Horsetail.
Very common in waste places etc. on Coll and Tiree.

E. sylvaticum L.
Only on Coll; in the vicinity of Arinagour and there plentiful.

E. palustre L.
Very common in wet places on Coll, Tiree and Gunna.

E. limosum L.
Common in lochs and bogs, Tiree and Coll.

E. trachyodon Braun.
We found a form just behind the dunes, south west of the Round House, which has cost us much study. As a result we have concluded that it must be referred to the present species. However, as soon as possible, we hope to procure more material to clinch our determination.

LYCOPODIACEÆ.

Lycopodium Selago L.
Scattered on the various hillocks on Coll; only on Dun an t'Sithein, Tiree.

SELAGINELLACEÆ.

Selaginella selaginoides Gray.
Not really rare; on fixed dunes, bare moorlands, grassy slopes on Coll, Tiree and Gunna.

Isoetes lacustris L. Quill-wort.
In various lochs on Coll; Loch Cliad, Loch a'Mhill Aird etc.

CHAROPHYTA.

Chara delicatula Agardh.
Lochs on Coll and Tiree.

C. aspera Willd.
Far from rare in lochs on Coll and Tiree.

C. hispida L.
Not common; in lochs on the same islands.

C. vulgaris L.
Abundant in lochs and streams on Coll and Tiree.

Nitella translucens Agardh.
Lochs near Kirkapoll.

APPENDIX

BRIEF DESCRIPTIONS OF NEW HYBRID ORCHIDS

By J. W. Heslop Harrison.

× **Orchis corylensis** mihi (= **O. maculata** var. **hebridensis** × **O. ericetorum**); parentibus intermedia; florum colore diluto-purpureo.

× **Orchis variabilis** mihi (= **O. maculata** var. **hebridensis** × **O. latifolia**); parentibus intermedia; foliis eis **O. latifoliæ** similibus; floribus roseis.

× **Orchigymnadenia Cookei** mihi (= **O. maculata** var. **hebridensis** × **Gymnadenia conopsea**); inter parentes eisque intermedia; 20 cm. alta; habitu aliquantulum flaccido; florum colore maculisque intermediis; calcare gracile quam ovario longiore.

Habitats; Isle of Coll; types in all cases in Heslop Harrison collection.

Recent Animal-Population Studies; and their Significance in Relation to Socio-biological Philosophy (Part I).

BY

D. STEWART MACLAGAN, D.Sc. (Edin.),
Ph.D., F.R.E.S.
Lecturer in Zoology, University of Durham.

(*M.S. received 9th June, 1941*).

CONTENTS.

I. INTRODUCTION.

To choose material which shall adequately represent this field of study is not an easy task, but perhaps the best way of attempting to do so is to organise the available evidence round a limited aspect of the subject, and to indicate the bearing thereon of recent notable investigations. A cursory examination of modern studies on problems of population shows that *density* is regarded as one of the most significant factors in the *biological* environment of organisms. It seemed worthwhile, therefore, to attempt a synthesis of the numerous, scattered, and important recent researches on the effects of density upon animal-populations and the *modus operandi* of the density factor. Before proceeding to the main subject, certain methodological matters demand comment. The development of experimental population-techniques has undoubtedly contributed towards more exact knowledge of animals *en masse;* indeed, to the extent of meriting or demeriting such titles as 'mass physiology' and 'population physiology,' but the experimentalist too often possesses an inadequate knowledge of the previous history of his biological material. It is apparent that, when experimenting with organisms in fluid media, great precision in the control of environmental factors, such as p H value, salt concentration, food supply etc., is essential. We experimental biologists cannot be too careful in the use of relatively standardised biological materials, if comparability and interpretability of results are to be obtained.

II. THE TREND OF POPULATION-GROWTH.

A century ago, Verhulst (1838) discovered that the S-shaped or 'logistic curve' (of the general formula, $y = \frac{k}{1 + e^{a-bx}}$ where y is the size of the population of age x, k is the upper asymptote, and a and b are constants) fitted the growth of human populations. This means that a population in a favourable environment grows exponentially at first, as Malthus maintained, but as the available space becomes occupied, density affects the death-rate or the birth-rate, or both, and the *growth-rate* of the population begins to decline. Eventually, the population oscillates about the upper asymptotic value, or it may decrease. The population of France has actually attained this last phase of the cycle. Pearl and Reed (1920) found that the logistic curve describes the population-growth of the United States; and later, Pearl (1925) showed that a

great variety of populations, growing under *experimental* conditions, conformed to the same 'law.' That few growing populations follow the logistic curve under *natural* conditions is due to the paucity of such environments which remain constant for any length of time, although Bodenheimer (1936) has shown that there is a good agreement between the curve and the seasonal growth of bee and wasp colonies, as well as the perennial growth of ant and termite colonies.

Now, as Pearl (1937) has pointed out, the three population-attributes that are directly relevant to the elucidation of significant problems of population, are (i) size, (ii) quality, and (iii) growth. Chapman (1928) has actually attempted to formulate a mathematical generalisation, integrating these factors, in order "that environmental factors be measured in terms of their effect in reducing the potential rate of increase." Borrowing his terms from Ohm's law of electrical conductivity, Chapman says that every species has its own 'biotic potential,' whilst the lowering of fecudity and fertility, the shortening of life-span etc., constitute the 'resistance' which the environment presents to the 'biotic potential.'

Electrical potential (E) ÷ Resistance (R) = Current (C)

The interaction of the factors E and R determines the value of C, i.e. the net rate of population-growth, which is ultimately determined by the population-density — a very important component of R, as shown in the following résumé. It should be realised that the Verhulst-Pearl equation merely describes the *growth* of the population, without contributing to an understanding of the biological significance of the phenomena, except in so far as the factors which mould the shape of the logistic curve do so in virtue of their density-dependent action, even although the factors themselves may be very diverse.

III. EFFECTS OF DENSITY UPON PROTOZOANS.

1. *Homogeneous Populations:*

The effect of crowding upon the *growth-rate* of a population seems to have been first studied experimentally by Woodruff (1911), working with *Paramaecium caudatum* and *P. aurelia*. He concluded that these protozoans excrete substances which are toxic to themselves, and that the excretory products play an important rôle in determining the growth-rate, and the rate of decline, of populations of these animals. Little further interest was taken in the subject until 1921,

when Robertson published a series of papers in which he sought to prove the opposite of the findings of Woodruff. He found that the rate of reproduction may be sixteen times as great when two protozoans (*Enchelys* sp.) are isolated in a single drop of medium as when one animal is present. To explain his results, Robertson (1922) postulated an X-substance, of nuclear origin, which is liberated into the surrounding medium and autocatalyses nuclear synthesis. Robertson called this phenomenon 'allelocatalysis.'

For some time no one could reproduce Robertson's results, including Cutler and Crump (1924) using *Colpidium colpoda*, Peskett (1925) using yeast, and Phelps (1935) using *Glaucoma pyriformis*. On the other hand, Yocom (1928) raising *Oxytrichia* on a sterile medium, did obtain an allelocatalytic effect, whilst Petersen (1929) in her experiments with *P. caudatum*, could produce positive and negative effects at will by manipulating volume relationships and food supply. The works of Barker and Taylor (1931) on *Colpoda*, of Smith (1932) on *P. caudatum* and of Johnson (1933 and 1936) on *Oxytricha fallax*, indicate that reproductive rate is controlled by the combined action of the number of organisms, volume of the medium and the food concentration, rather than by the independent action of any single factor. This would explain the results of Mast and Pace (1937) who found that, as the density of *Chilomonas* increased, the frequency of fission increased to a maximum and then decreased to zero. These researches also indicate that the rate of reproduction depends upon whether the organisms themselves *tend to shift the environmental conditions* away from or towards the optimum. Thus, where the bacterial concentration is supra-optimal, two protozoans can reduce the numbers to the optimal density quicker than one, and likewise respecting environmental factors such as pH value, carbon dioxide concentration, and oxidation-reduction potential. This recent work confirms the phenomenon which Robertson called 'allelocatalysis,' but not his theory.

The rôle of waste-products as limiting factors in the growth of protozoan populations is difficult to evaluate from this work, and Phelps (1936) has obtained concentrations of *Glaucoma pyriformis* over a thousand times greater than those observed in other investigations, before the effects of excretory products on rate of division were noticed. The organism was grown in pure culture, to a density of half a million per cubic centimetre.

2. *Heterogeneous Populations:*

Recently, Gause (1934) has worked with mixed populations of yeasts, mixed populations of protozoans feeding on the same bacterial food supply, and populations of the predator-prey type e.g. *Didinium* feeding on *Paramaecium*. He found that when two species compete in identical niches for the same food the one that is less adapted to the environment is ultimately expelled from it, but when each species has the advantage of its proper niche both may co-exist indefinitely. An interesting feature which Gause demonstrated experimentally was that the classical predator-prey oscillations, of the Lotka-Volterra type, occur only when the searching of the predator is limited or at random; otherwise, and unless the prey has protective niches, the predator completely destroys the prey and itself dies of starvation. The factors limiting the growth of these experimental populations were, sometimes, exhaustion of the means of subsistence, and sometimes, susceptibility to the accumulated products of metabolism, depending upon various other environmental conditions, such as pH value and aeration of the medium. This is undoubtedly a valuable line of attack on problems of population, but the method requires reinforcement by more detailed experimental analysis of the factors involved; and while it demonstrates that the bio-mathematical theories of authorities such as Thompson (1924), Lotka (1925), Volterra (1926), and Nicholson (1933), can be realised under appropriate experimental conditions, it gives little indication of the significance of these theories in relation to actual events occurring in Nature.

In all these experiments there are certain practical difficulties associated with the stabilisation of a fluid medium containing living organisms, the chief of these being (i) the control of the bacterial population in the culture — when this is the food-supply, (ii) the rapid diffusion of excretory products in a fluid medium, and (iii) the presence of minute quantities of toxic substances dissolved from glass containers.

Hence, to obtain convincing evidence of a true density-effect on the growth of populations, it is desirable to utilise a non-fluid medium which can be renewed as often as is necessary. The following results show that even in the presence of abundant food, in the absence of deleterious waste-products, and under optimum physical conditions, animal-populations offer an internal resistance to their own growth, after the attainment of a certain population-density.

IV. EFFECTS OF DENSITY UPON INSECTS.

1. *Fecundity:*

The first convincing experimental evidence of a true density-effect was produced by Pearl and Parker (1922), working with the Fruit-fly, *Drosophila*. These collaborators found that the number of adult flies produced per mated pair fell continuously, in a very definite manner, as the number of pairs per half pint bottle increased from one to fifty. They concluded that fecundity is the biological attribute which is chiefly affected, in virtue of the inability of *Drosophila* to feed and oviposit normally when disturbed. Further evidence is available from the studies of Chapman (1928). Working with the Flour-beetle, *Tribolium confusum*, in a constant environment, Chapman demonstrated that, irrespective of the initial density, equilibrium is eventually attained at a density of approximately forty-three beetles per gram of flour. After this, the population remains relatively constant, provided the flour is renewed frequently enough to remove waste-products and maintain an abundance of food. Chapman's data were subsequently analysed by Gause (1931), who showed that the growth of the *Tribolium* population conformed to the logistic curve.

Holdaway (1932) found that the size of the asymptotic, or balanced, population was not independent of the atmospheric moisture, since, by maintaining a population at a relative humidity of twenty five per cent until it became relatively constant, and then transferring it to an atmosphere of seventy five per cent saturation, growth of the population recommenced and continued until a higher level of stability was attained. To explain these results, Holdaway suggested that the larvae and adults of *Tribolium* utilise the eggs and pupae as sources of moisture, but when the flour itself contains more moisture there is less need of the cannabalistic action. It seems, however, that the real explanation is to be found in the effects of the higher humities upon the life-cycle of the beetles, in reducing the larval period and increasing fecundity and longevity of the adults.

Chapman (1928) had concluded that equilibrium is attained when the biotic potential is equalled by the environmental resistance, and that the lack of population-increase is not due to the absence of eggs or their infertility, but to the eating of eggs and pupae by the adult beetles. It was shown, however, (MacLagan, 1932) from an analysis of Chapman's own data, and by independent experiment, that this

explanation of the stationary character of the population is only partly correct, since, with increasing density there is a rapid reduction in the number of eggs oviposited and a considerable decrease in their fertility.

Beetles per Gram of Flour	1	2	4	8	16	32
Eggs per Beetle per Day (8 days)	0.94	1.43	1.04	0.56	0.54	0.35

Table I:— Effect of Population Density upon Fecundity of *Tribolium confusum* (MacLagan, 1932).

A particularly interesting feature was the proven existence of an *optimum* density, above and below which, oviposition takes place at a reduced rate. Comparison with Chapman's results revealed that this optimum density is not absolute, and can be shifted by changing the environment, such as the temperature-humidity conditions, or by the development of strains better adapted to high densities. Commenting on this, Ford (1937) says, " This is of importance in that it indicates a factor, the ignoring of which has occasionally given rise to needless controversy . . . the behaviour of a *Tribolium* population depends not only upon the immediate conditions of the experiment but also to a large extent on the previous history of the individuals . . . MacLagan's stock culture had been maintained for six months under conditions of intense crowding."

In order to confirm the operation of this density effect in other species, additional experiments were performed with two species of grain weevil, *Sitophilus (Calandra) granarius* and *S. oryzae*. These insects differ from *Tribolium* in the deposition of their eggs, in that, instead of distributing them at random in the floury medium, the eggs are inserted into the grains of various cereals. This reduces the chances of mechanical injury to the eggs, by the insects themselves, and renders the accumulation of carbon dioxide even less probable than in a frequently changed environment of flour. The stock-culture of weevils was kept for over six months under highly favourable conditions of temperature and humidity but was subjected to intense crowding, thereby ensuring an inbred strain of weevils, on account of the selective elimination which occurs in these circumstances.

Experimental environment was set up with 0.25, 0.04, 1.0, 2.0 . . . 32.0 weevils per gram of wheat-grains, and after sixty-four days the number of weevils in each experimental universe was counted and expressed as adult progeny per weevil. It was found (MacLagan, 1932) that the two variables, population-density and progeny per weevil, exhibit a hyperbolic relationship, and that although the progeny per weevil decreases as the number of grains at her disposal decreases she utilises a greater percentage of the total available number, at least up to a certain degree of crowding; but when the density is such that there is only one grain of wheat to every four female weevils (in a population consisting of equal numbers of both sexes) oviposition practically ceases. Another fact of interest from these experiments is that the female *Sitophilus* will not lay the maximum number of eggs until the number of grains available is at least eight times that actually utilised. This occurs when there are four hundred grains per female weevil. Further, if the number of grains be increased to eight hundred per female weevil there follows a reduction in the number of progeny, thus clearly indicating an optimum density for rate of oviposition, and substantiating the evidence derived from our analysis of the *Tribolium* experiments.

2. *Interspecific Reaction:*

In pursuit of further understanding of the density-factor the next step was to test the effect of one species upon another, using the Angumois Grain Moth *(Sitotroga cerealella)* and the Grain Weevil *(Sitophilus granarius)* as the interacting species. In environments of one thousand grains of wheat the following results were obtained.

Weevils.	Moths.	Reduction (%) of Weevil Progeny.
40	10	1.2
10	20	24.0
10	40	48.2

Table II.— Interspecific Reaction of the Weevil *(S. granarius)* and the Moth *(S. cerealella)* — (MacLagan, 1932).

A particularly interesting feature of these figures is, that, although the reproductive rate of the weevils is significantly lowered by the presence of the moths, the reduction is *less* than that produced by a similar number of weevils. Whatever the ultimate nature of the factor responsible for these density-reactions it is not species-specific, and the effect can be brought about by other species in the environment, despite the absence of direct competition for *food* or *oviposition-sites*.

3. *Copulation-frequency:*

In a subsequent study (MacLagan and Dunn, 1936) involving a detailed experimental analysis of the factors which constitute the internal resistance of a population to its own growth, confirmatory evidence of the effects of density on *Sitophilus granarius* was obtained with *S. oryzae*, and a phenomenon which had hitherto escaped attention was investigated, namely, the effect of population-density upon frequency of copulation. An inbred strain of *S. oryzae* was used; and in order to standardize the experimental universe, as well as to facilitate observation of the weevils, the containers held just the requisite amount of wheat when the grains were disposed in a single layer. Six hourly observations of the number of females *in copula*, in different densities, were made each day for five days, with the following results.

Grains per Weevil	200.0	50.0	25.0	12.50	1.56	0.78	0.39	0.19
Weevils per grain	0.005	0.02	0.04	0.08	0.14	1.28	2.56	5.12
Copulation-frequency'	22.80	31.97	33.06	24.23	5.89	2.56	2.01	1.60
	'Average Percentage of females *in copula* (hourly observations).							

Table III.— Effect of Population Density upon Frequency of Copulation *(S. oryzae)* (MacLagan & Dunn, 1936).

The existence of an optimum density for *frequency of copulation* was therefore clearly demonstrated. Additional experiments have shown that this optimum is not absolute, and can be shifted by altering the physical or biotic factors of the environment, such as the temperature or the sex-ratio.

4. *Mathematical Analysis*:

In view of the great definity with which the effect of density appears, a brief mathematical analysis of the data, at this point, may facilitate interpretation of these results. Almost a century ago, Farr (1843) developed an equation which described the relation between the density of human populations and their death-rates, while Pearl and Parker (1922) found that the same equation (to which a curve-fitting refinement was added) expressed the relation between crowding and reproductive rate in *Drosophila*. This old law of Farr states that $R = cD^m$, where R is the death-rate, D is the population-density per unit area, and c and m are constants. It was also shown by MacLagan (1932) that the effect of crowding upon the net reproductive rate of *Sitophilus granarius* can be described by the same equation, $Y = a X^b$, where Y represents progeny per weevil, X the space per individual and a and b are constants. Essentially the same equation, $Y = aX^{-b}$, was found to describe the relation between population-density and frequency of copulation in *Sitophilus oryzae*, at least for densities above the optimum (MacLagan & Dunn, 1936), where Y represents frequency of copulation and X the number of weevils per grain.

5. *Optimum Densities:*

This brings us to a consideration of the explanations put forward for the existence of an optimum density for rate of reproduction in *Tribolium and Sitophilus*. Dealing first with the effects of density upon the frequency of copulation, it is fairly obvious that the reduction of frequency in densities below the optimum is due to the decreased opportunities of meeting of the sexes. The reduction in frequency when the population attains a certain density is apparently due, primarily, to the effects of excessively numerous mutual contacts. The weevils are very sensitive to mechanical stimulation, including contacts with other individuals, and it seems not unreasonable to assume that excessive contact-stimulation, in addition to preventing favourable opportunities for copulation, may provoke a reaction which depresses the stimulus to copulation. The continuous fall in the rate of oviposition despite an optimum for frequency of copulation indicates that the fall is not a direct result of the decrease in copulation-frequency. This factor is indeed masked by a more powerful influence depressing the rate of oviposition, namely, the increased contacts between the weevils. Although the primary effect is mechanical, it operates organically through the reduction of the times available for

feeding, ovipositing and resting, thereby causing adverse effects upon the physiological processes of reproducton (MacLagan & Dunn 1936).

In an attempt to explain why intermediate densities of *Tribolium confusum* have a greater initial increase than higher or lower ones Park (1933) says: "This was found to be due to the interaction of two factors. The first was egg-eating, which was most intense in cultures of high density; the second factor was the question of frequency of copulations. Since more copulations were occurring in concentrated populations, this fact favoured greatest increase in maximal sized groups. The interaction of these factors . . . would cause an intermediate-sized population to have the greatest initial increase." Unfortunately, Park overlooked the possibility of a decreased copulation-frequency above a certain degree of crowding.

6. *Host parasite Relationships:*

Interesting contributions to the study of population-densities, especially in relation to the dynamics of host-parasite relationships, have been made by economic entomologists. As a result of large scale attempts to utilise two species of the parasitic hymenopteran, *Trichogramma*, (oviposits in the eggs of its host) Flanders (1935) found that with increasing density of the host the number of *progeny per parasite* increased until a maximum was reached. In another series of experiments, in which the number of parasites was varied instead of the host-density, the number of *progeny per parent* decreased with increase in the number of parasites liberated. The data also indicate that for single generations the *maximum percentage of parasitism* occurs when the number of available hosts approaches the reproductive potential of the parasite. At very high host-densities, the percentage of parasitism decreases because the reproductive potential of the parasite is limited. Nearly eight thousand hosts were used in these experiments.

Another investigator who has conducted extensive researches on insect-parasitism (Salt, 1936) concludes that, as the density of the *Trichogramma* population increases, the following effects are observed:—(i) the number of hosts that escape decreases, (ii) the total parasite progeny reaches a maximum and then decreases, (iii) the progeny of the individual parasite decreases. Similarly, the data of Lloyd (1938) on the egg-parasite, *Ocencyrtus kuvanae*, show that, under the conditions of his experiments, the fraction of the host-

population that is discovered rises as its density diminishes. This recalls Flanders' statement regarding the percentage of parasitism at high host-densities. All these conclusions are entirely comprehensible if one bears in mind that the ultimate result depends upon the relative concentration of host and parasite, the reproductive potential of the parasite, and its sphere of action. Moreover they are in complete accord with the previously cited results derived from the experimental analysis of the growth of populations of *Tribolium confusum* and of *Sitophilus (Calandra) granarius* (MacLagan, 1932).

A convincing demonstration, of the mathematical relationship between density of the host and relative increase of a parasite, has been given by Smirnov and Vladimirov (cited by Gause, 1934), by allowing pupae of the dipteran, *Phormia groenlandica,* to be parasitised by the wasp, *Mormoniella vitripennis.* As the density of hosts increases the progeny per pair of parasites increases also, but at a decreasing rate, until a maximal value is attained; according to the equation, $y = N\ (1 - e^{-kx})$ where y is the progeny per female parasite, x is the density of hosts, and N is the asymptotic value of y. This is fundamentally the same equation as the one developed by Deltheil, at the instigation of Thompson (1924), who desired a general formula to express the probable percentage of parasitism after the deposition of x parasites in N hosts, when the parasite distributes its progeny at random among the hosts. Nicholson (1933), utilising the same equation (which he calls " the competition curve ") has reared a remarkable edifice of biological theory concerning the interaction of animal populations, on the basic assumptions that, in general, animals appear to be limited in density, either directly or indirectly, by the difficulty they experience in finding the things they require for existence or by the ease with which they are found by natural enemies. The relation between the reduction of the success of searching animals and intensity of competition finds quantitative expression in the " competition curve," which has a general application to all forms of random searching. Thus, competition limits the density of the population and holds it in a state of balance with the environment. Such are Nicholson's views *in nuce* on the natural limitation of population, and, although awaiting complete observational and experimental verification, they undoubtedly constitute a notable contribution to biological philosophy, were it only for the wealth of imaginative talent brought to bear upon the problem.

7. *Growth and Longevity:*

Although it seems that the harmful effects of crowding upon *longevity* and *rate of growth* are of minor significance in comparison with the effects upon reproduction, nevertheless, in so far as they affect the duration of the reproductive period these factors must have some effect upon the growth of the population. There is little doubt that insufficient aeration and the accumulation of excretory products are inhibiting influences for many organisms which live in fluid media, whether they be planarians (Goetsch, 1924), snails (Crabb, 1929), echinoderms (Peebles, 1929), or fish (Willer & Schnigenberg, 1927). Adolph (1931) found that crowded tadpoles stop growing much sooner than isolated individuals, and that partitioning the animals from each other, without changing the total volume, eliminated the adverse effect. In a further attempt to assess the relative significance of chemical and biophysical factors in the causation of this effect in crowded tadpoles, he found that the differences between crowded and isolated individuals were as great in running water as in still water, thus confirming the earlier work of Bilski (1921), who concluded that the depression of growth was a function of the group-stimulation possibilities resulting from repeated physical contacts.

Almost a century ago, Farr (1843),—' the father of vital statistics '— showed that there is a well defined relationship between the density of human populations and their death-rates, and he anticipated the trend of modern biology to the extent of elaborating a mathematical formula which conformed to his findings (see previous section for details). Brownlee (1915) discovered that this generalisation of Farr is a definite law which operates independently of hygienic or other improvements. The most complete *experimental* analysis of the effect of density upon longevity is that of Pearl, Parker and Miner (1927). These workers found that the mean duration of adult life of *Drosophila* is profoundly affected by the initial density of the culture, and, most interesting of all their conclusions, that there is an optimal density above and below which the specific death-rates are higher. This brings us to a consideration of another aspect of population density, namely, the adverse effects of *undercrowding*.

8. *Discussion*:

We have already examined the evidence concerning the existence, for various organic responses, of an optimum density of population (intermediate between maximal and minimal densities) and, in consequence, have been convinced

that such optimal densities certainly exist for the reproductive rate of *Calandra* (MacLagan, 1932) and *Tribolium* (Park, (1932), for the longevity of *Drosophila* (Pearl & Parker, 1922), and for the copulation-frequency of *Sitophilus* (MacLagan & Dunn, 1936). The question now arises, to what extent does this phenomenon of minimal densities not necessarily being optimal, occur throughout the animal-kingdom?

If we regard all environmental factors, biotic and physical, as being potentially capable of operating at sub-optimal and supra-optimal concentrations or intensities, there appears to be no good reason, *a priori,* why biotic factors should differ in this respect from physical factors. Indeed, all the available evidence supports the contention that educement of the maximum response of various physiological processes of animals *en masse* requires a particular combination of factors, physical (temperature, salinity, etc.) and biotic (density of organisms, sex-ratio, etc.) of which the latter play an important rôle in the self-limitation of population-growth in virtue of their density-dependent action. Thus, in addition to the above examples, it is now known that small groups of sea-urchin eggs develop more rapidly than isolated eggs (Frank & Kurchina, 1930), that honey-bees under conditions of moderate crowding live longer than isolated individuals (Kalabuchov, 1933), that there is an optimum degree of crowding for the growth-rate of male mice (Vetulani, 1931), that isolated larval mealworms do not grow so rapidly as moderately crowded ones (Michal, 1931), and that the growth of small tadpoles is retarded by undercrowding as well as by overcrowding (Podhradsky, 1932).

V. MASS PROTECTION.

That an optimum population-medium relationship is apparently of universal biological significance receives support from other phenomena of a more generalised character, associated with the survival value of aggregations of organisms exposed to adverse or toxic conditions. The literature on this expanding subject has been ably reviewed by Allee (1931, 1934), who is an authority in this field of study, and it is not intended to do more than indicate the bearing of these investigations on the subject in hand. Two kinds of toxicity are recognised in relation to mass protection of the aggregants: — (i) that caused by the presence of an unusual constituent in the medium, e.g. collodial metals; and (ii) that caused by the absence of a normal constituent e.g. hypotonic sea-water.

The discovery was originally made by Bohn & Drzewina (1920) that, within limits, the greater the number of animals in groups exposed to toxic conditions the greater is the protection afforded to the members. Pavlov (1925), experimenting with the crustaceans, *Gammarus pulex* and *Artemia salina*, found that for a given salt-concentration the percentage survival increases with the volume of the medium and the density of the population. Carpenter (1930) found that, in a solution of constant volume and molar concentration, the survival times of various fishes varies directly with the mass of the fish. The work of Fowler (1931) shows that the increased survival of numbers of *Daphnia pulex* compared with isolated individuals, when exposed to various solutions of electrolytes, is due to an increased carbon dioxide tension, causing a reduction in oxygen-consumption with an accompanying decrease in sensitivity to the toxic effects of the solution. This explanation is in complete accord with the better known dictum of Child (1915), that when animals are exposed to conditions of high toxicity, with insufficient time for acclimatisation, depression of metabolism has survival value. It is also known that the carbon dioxide produced by animals in an abnormally alkaline 'medium' weakens the toxic concentration by forming carbonates and water, so that aggregates of such organisms have survival value.

Of the nature of the protection furnished by a mass of animals against colloidal silver there is little doubt that it is due to the more rapid removal of the toxic agent by the group, either by absorption on the slime secreted by some animals, and in lesser degree thrown out of suspension by the salts in faeces and urine (Allee & Bowen, 1932). There is no evidence of a mysterious "autoprotective secretion" (Drzewina & Bohn, 1928) and the protection is not species-specific, as the presence of cladocerans, snails, leeches, or certain echinoderms, protects planarians from the toxic effects of colloidal silver.

Regarding the toxicity due to the absence of a normal constituent of the environment, Castle (1928) found that when small fragments of *Planaria velata* were placed in a large volume of distilled water, they usually died, whereas in smaller volumes as many as seventy five per cent survived. Allee (1928, 1933) has conducted extensive researches on the survival of a marine turbellarian, *Procerodes wheatlandi* in hypotonic sea-water and in tap-water. The worms live longer in fresh water, (i) if present in numbers, (ii) if placed in fresh water which has been inhabited by *Procerodes*, and especially, (iii) if placed in fresh water containing disintegrated *Procerodes*,

even although the medium has been boiled and filtered. An explanation of these phenomena is linked with the broader subject of biologically conditioned media, of which a brief outline follows.

VI. BIOLOGICAL CONDITIONING.

1. *Heterotypic:*

Organisms excrete and secrete into the medium of their existence various substances of which the biological effects on themselves and on other species are often profound. Indeed. it is a basic ecological generalisation that the accumulated waste-products of a species limit its tenure of a habitat and simultaneously prepare the way for the entrance of other species. Thus, copepods and ostracods flourish in dying cultures of *Daphnia* (Warren, 1900); the addition of cladocorans to the medium stimulates the growth of snails (Crabb, 1929); and there is the classical sequence of fauna in a protozoan infusion, the dominant organism at the surface appearing in the order—*Colpoda, Paramaecium, Vorticella,* and *Amoeba* (Woodruff, 1912). There has long been a consensus of opinion amongst aquarists that snails are beneficial to fish-culture, and it has now been ascertained (Shaw, 1932), that the fish, *Platypoecilus maculatus,* grows more rapidly in filtered well-water which has been inhabited by mussels for twenty four hours than in the unconditioned water, even although the former had apparently no food-value. So much for *heterotypic* conditioning.

2. *Homotypic:*

Apart from the well known adverse effects of *homotypic* conditioning there is evidence that *slight* homotypic conditioning may exert favourable effects on organic processes. Shaw (1932) found that, in certain circumstances, fishes and *Ambystoma* larvae regenerated tails more rapidly in homotypically conditioned water than controls in unconditioned water. Concerning the effective factors in biologically conditioned media it is known that highly conditioned aquarium-water reveals a strong fluorescence under ultra-violet radiation — a phenomenon only slightly present in natural fresh waters and absent from distilled water (Merker, 1931) — but before any positive conclusion can be drawn, it will be necessary to evaluate the food values of the conditioned media, as it is common knowledge amongst biologists that extremely minute quantities of certain substances are capable of exerting

highly significant effects upon organic processes. In explanation of the *Procerodes* experiments, it was suggested by Allee (1931), that since worms isolated into water conditioned by living organisms tend to lose electrolytes less rapidly than controls in hypotonic sea-water, the effect of conditioned media may be due, in some instances, to the retention within the organism of substances necessary for continued existence, rather than to the presence of any " protective " materials.

VII. EFFECTS OF DENSITY UPON THE SEX-RATIO.

1. *Cladocera*:

Another interesting phenomenon associated with increasing density of animals is a change from parthenogenetic to sexual reproduction and an increased production of males. It has, of course, been pointed out several times that in many animals a 50:50 sex-ratio seems biologically inexplicable, since the male is the sexual equivalent of thousands of females. The production of males in Cladocera (normally parthenogenetio) has been a subject of experimentation and speculation ever since it was suggested that the sex of these animals is environmentally determined (Lubbock, 1857). Later, the succession of parthenogenetic and bisexual forms was ascribed to an innate rhythm (Weismaun, 1879). Succeeding decades have witnessed a spate of publications on the factors influencing the appearance of bisexual forms, some stressing the importance of poor nutrition (de Kerherve, 1892; Woltereck, 1909; Papanicolau, 1910); others stressing the accumulation of excretory products (Kurz, 1874; Langhans 1909; Hartmann, 1919); and still others recognising the importance of both food and temperature, (Issakowitsch, 1905; McClendon, 1910; Tauson, 1930). Tauson emphasizes the importance of pH value also in determining the type of reproduction. Grosvenor and Smith (1913) found that while there is a temperature effect upon the production of males, crowding significantly increases the proportion of males in *Moina macrocopa* (bacteria feeder), and it was later reported by Smith (1915) that crowding operates on *Daphnia pulex* (algal feeder) through the presence of excretory materials in minute quantities. This conclusion was amply confirmed by Banta and Brown (1923), who have conducted extensive researches on the problem, and are of the opinion that the production of males in several species of Cladocera is ordinarily associated with a dense population, the causative factor being the accumulated waste-products of metabolism. These

substances are readily oxidisable and lack species-specificity (Banta & Brown, 1929). Moreover, retarded development of the mothers, induced by low temperatures, chloretone, or cyanide, stimulates the production of males, whereas low concentrations of ethyl alcohol, or increased aeration treatments of the medium, have the opposite effect (Banta & Brown, 1930). Thus, the production of males is associated with a lowered rate of metabolism. It has since been found that *intermediate* dilutions of bacterised filtrate result in the highest percentage of males in *Moina macrocopa,* and that the bacteria do not act simply by adsorption (Stuart & Banta, 1931). More recently, Stuart and his co-workers state that shaking the mothers when the sex of the offspring is labile significantly decreases the percentage of males (Stuart, Cooper & Miller, 1932); whilst the greatest production of males occurs below 14°C, and between 21°C and 30°C, when the mothers are only *moderately* crowded. That is to say, there is an optimal density for production of males within certain temperature limits (Brown & Banta, 1932).

2. *Insecta:*

Differences in sex-ratios associated with differences in population-densities are not confined to Cladocera, however. Several species of grasshoppers harbour nematode parasites of the family Mermithidae, and if only three or four of the eggs of the parasites are ingested by a grasshopper they all develop into female worms, but if twenty or more eggs are swallowed the resulting worms are all males (Cobb, Steiner & Christie, 1923). A similar result was found in mermithids belonging to four different genera, parasitising insects of four different orders, the proportion of male parasites always increasing with the intensity of the infestation. It seems that, in this instance, sex is largely determined through the apportionment of the nutritive value of the environment. In flies of the genus *Miastor* all the individuals are ordinarily females, but excessive crowding causes the appearance of males in the population (Harris, 1923). In this case, the *modus operandi* of increasing density upon the sex-ratio is not through a differential sex-mortality, as appears to happen in *Trichogramma* (Salt, 1936).

An interesting viewpoint recently propounded by Banta (1937) is that considering the reproductive superiority of an all-female race, such races may have a biological advantage under conditions of intense competition, so that animals which live in habitats that are restricted in space *(Cynipidae,*

Miastor), or in time (*Cladocera* in a temporary pond) tend to eliminate the male sex. Thus, crowding not only influences sex-ratios but promotes the evolution of thelytokous races. The point at issue is highly controversial.

VIII. CONCLUSION (Part I).

From the available mass and variety of *experimental* evidence on the intra-specific activities of organisms it is apparent that population-density is of the utmost biological significance; and, as Bodenheimer (1938) remarks, "it is to Pearl's permanent credit that he discovered the basic ecological importance of the density-factor in population-growth and in animal-populations in general." In this connection it is well to recall the viewpoint of Allee (1931) that the first advance toward social life is toleration of the presence of other animals in a limited space, where they have collected as a result of tropistic reactions to their environment, and the next advance occurs when these groupings have survival value for at least some of the individuals composing them. The potentiality of social life is, therefore, inherent in animal-protoplasm, even though its first manifestations are merely those of a slight mutual dependence or an automatic co-operation. That there is an optimum degree of crowding for various organic processes is apparently a fundamental biological principle, and the more recent evidence of the beneficial effects of a certain degree of crowding does not minimise the importance of the better known adverse effects of overcrowding.

Thus far we have considered the evidence and the various explanations of the effects of density in experimental populations of animals. It is very obvious that a mass of data has accumulated within the last twenty years, and that the time has arrived for an attempt to elaborate ecological principles. Part II will, therefore, include a discussion on the rôle of density in the limitation of *natural* populations, a critical summary and synthesis of density effects, and an examination of their significance in relation to socio-biological philosophy; the writer being in full agreement with Woodger (1929) that " we are in danger of being overwhelmed by our data, and of being unable to deal with the simpler problems first, and understanding their connection. The continual heaping up of data is worse than useless, if interpretation does not keep pace with it."

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AN ECOLOGICAL SURVEY OF A BEACH ON THE ISLAND OF RAASAY.

BY

W. STEPHENSON, PH.D.

Introduction.

The work was carried out during part of the King's College Zoological Expedition to the Inner Hebrides, from August 14th to August 28th, 1937.

It was thought desirable to undertake an accurate ecological survey of a Hebridean beach for the sake of comparison with the results of similar surveys on other parts of the coast.

The beach chosen faced south into Churchton Bay, Island of Raasay, and consisted of a small sheltered harbour.

Topographical Survey.

The only apparatus available was a military compass, a surveyor's tape and a yard rule, and a tolerable degree of accuracy could only be obtained by persistent checking of results.

The basis of the survey was the Admiralty chart of the area, which was copied on a much larger scale by subdivision into small squares.

To check this outline map, the distances and bearings of a series of prominent reference points, one from another, were measured, and the rough map corrected accordingly. To obtain the heights of the various parts of the beach, suitable tidal levels were marked on the beach by means of piles of stones. The positions of these piles on the map were then obtained by taking their distances and bearings from at least two of the previous reference points. By joining up these new points on the map, a contour line was obtained, showing the part of the beach at this particular level. This was repeated at different water levels, and a series of contour lines was obtained, shown on Map 1 as the a, b, c, d, e, f, g, h, j, and k lines. The state of the tide when these lines were marked is shown in Table 1 column 2, and in column 3, the method of measuring the differences in height between the lines is shown, while in column 4, the observed differences in height between the different lines is given. The estimated error in

measuring the differences in heights between adjacent contours is about 0.1 ft., and the estimated error between the a. and k. contours about 0.5 ft.

Correlation of Height above Datum with percentage exposure.

Since the contours were chosen arbitrarily it is necessary to relate them to accepted standards of measurement, i.e. with tidal levels and percentage exposure.

The beach was only under observation for a fortnight, and so extensive tidal measurements could not be taken. Moreover, the nearest station for which predicted data were available was Stornoway, and it was observed that the predicted data for Stornoway did not agree with the observed readings at Raasay, as shown by the differences between columns 4 and 5 of Table 1. Comparing these columns as in column 6, it appears that, allowing for inaccuracies due to winds and errors of measurement, the tidal range at Raasay is about 1.1 times that at Stornoway.

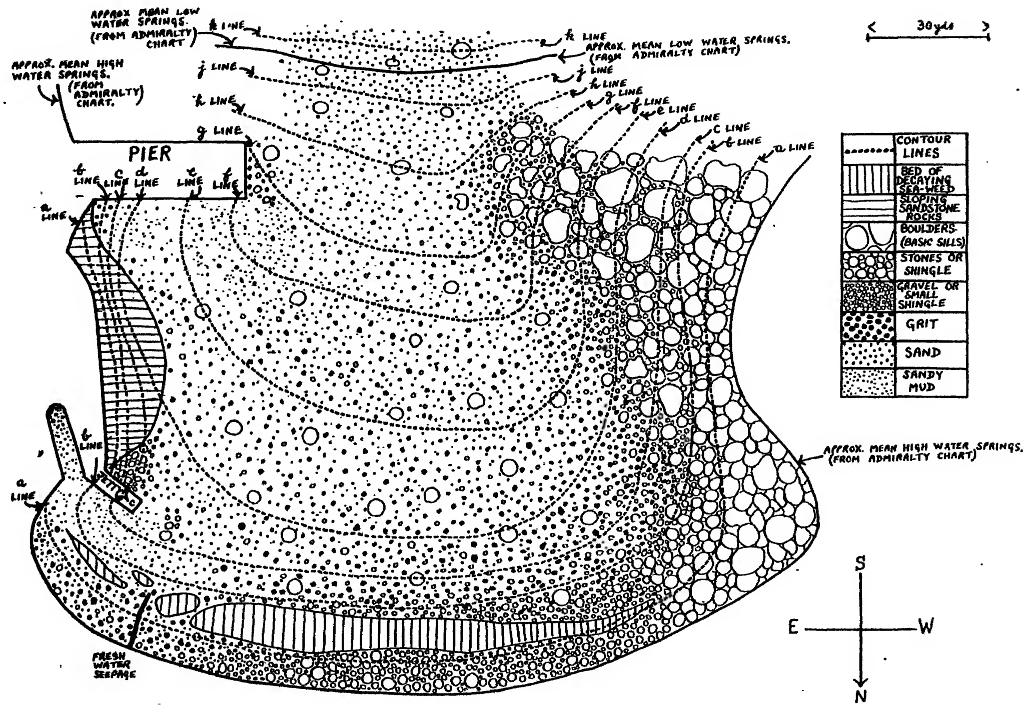
Knowing this, it is possible to calibrate the contour lines on the beach at Raasay with the tidal measurements as predicted at Stornoway. Thus the Mean Tide Level on the beach at Raasay was observed to be below the d. line, one third of the distance between this and the next lowest (the e.) line. The M.T.L. at Stornaway over this period was 7.5 ft. above datum, and thus we can say that the level on the beach at Raasay mentioned above corresponds to a height of 7.5 ft. above the Stornoway datum.
Then a distance of x ft. above or below the M.T.L. at Raasay will correspond to a distance of x/1.1 ft. above or below 7.5 ft. above datum at Stornoway. The heights of the contour lines on the beach with reference to the Stornoway datum, as calculated by the above method are shown in Table 1.; column 9, intermediate figures being given in columns 7 and 8.

Correlation of Height above datum with percentage exposure.

The method employed was similar to that employed by Colman (1). The times and heights of the tides were obtained from the Admiralty Tide Tables for Stornoway for the periods Feb. 25th to March 12th, May 25th to June 8th, Sept. 4th to Sept. 20th, Dec. 17th to Dec. 31st.

These were plotted with times as abscissae, and heights as ordinates, the points being joined in a smooth curve. Then at different heights above datum, the total times over the four periods of the year when the positions were uncovered by water was measured. The sum of these times divided by the total

MAP I



Showing the contour lines used in the topographical survey, and also the main topograpical features of the beach.

time during the four periods, converted to a percentage, was taken as the theoretical percentage exposure. The results are probably accurate to about 2%, and are expressed graphically on Figure 1, where the theoretical percentage exposure is plotted against height above the Stornoway datum. From this figure the values in Table 1 column 10. were obtained, showing the theoretical exposures at the heights of the different contour lines.

Estimation of Splash.

The above results only give the theoretical percentage exposure to the atmosphere, and make no allowance for splash, the significance of which has been stressed by Colman (1). An estimation of splash on the beach under consideration was difficult owing to the fact that the weather was exceptionally calm during the whole of the period when the survey was carried out. The splash zone which was actually observed was only about 2-4 ins. vertically, and allowing for the sheltered nature of the coast in general, and the beach in particular, probably an average splash zone of 1.0 ft. would be adequate. This estimate is only a guess, and the error may be as great as 50%.

A splash zone of 1.0 ft., has the effect of raising the M.T.L. by 10. ft. so that the theoretical exposure at x ft. above datum will be the actual exposure at x+1 ft. above datum. The corrected exposures, allowing for splash are given in Table 1, column 11, and the results are expressed graphically on Figure 1.

From the above column, by interpolation, it is possible to find the percentage exposure to the atmosphere at any part of the beach, and this exposure is probably accurate to about 5%. This is also the limit of accuracy with which the distribution of the various inhabitants could be investigated.

Main Topographical Features of the Beach.

To facilitate the accurate observation of these features, and also to make the observation of the horizontal distribution of the fauna and flora more accurate, the areas between contour lines were subdivided by means of intersecting lines into a series of sectors.

Further mention of this subdivision is not necessary, except that it was by using these sectors that an accurate topographical survey could be made. The surface conditions in each small area were noted and these results plotted on the map. The final result is shown diagrammatically on Map I.

TABLE 1.

1	2	3	4	5	6	7	8	9	10	11	12	13
Contour line	State of the tide	Method of measuring heights between contour lines	Observed differences in heights between contour lines in feet	Predicted differences in hts. from Stornoway tables	Ratio of observed ht. to predicted ht.	Ht. in ft. above or below M.T.L. at Raasay	Corresponding ht. in ft. above or below M.T.L. at Stornoway	Corresponding ht. above Stornoway datum	Theoretical percentage exposure	Actual percentage exposure, allowing for splash	Average horizontal distance in ft. between lines in the middle of the beach (to nearest 3 feet)	Average slope of the beach at heights mid-way between the contour lines
a	H.W.M. 22/8/37	By height of the water against a small pier				8.5	7.8	14.4	99	95		
			4.0	3.6	1.1						36	0.111
b	H.W.M. 20/8/37					4.5	4.2	11.7	82	72		
			2.0	1.8	1.1						24	0.083
c	H.W.M. 14/8/37					2.5	2.3	9.8	64	56		
			2.0								36	0.056
d				4.8	1.25	0.5	0.5	8.0	52	48		
			2.0								84	0.024
e						-1.5	-1.4	6.1	44	37		
			2.0								90	0.022
f	L.W.M. 14/8/37	By height of the water against boulders				-3.5	-3.2	4.3	30	22		
			1.5	1.5	1.0						45	0.036
g	L.W.M. 19/8/37					-5.0	-4.6	2.9	19	11		
			1.1	1.0	1.1						57	0.019
h	L.W.M. 20/8/37					-6.1	-5.6	1.9	11	5		
			1.0	1.0	1.0						54	0.019
j	L.W.M. 21/8/37					-7.1	-6.6	0.9	5	1		
			1.0	1.2	0.8						45	0.022
k	L.W.M. 24/8/37					-8.1	-7.5	0.0	1	0		

In distinguishing the different types of substratum, the standards given in Table 2 were adhered to. Of the types specified, the grit and various types of sands were separated by sieves of 10, 30, and 60 meshes to the inch, while mud was distinguished from fine sand by its ability to remain suspended in sea-water for longer than 90 seconds.

TABLE 2.

Type of substratum	Max. dia. (in mms.)	Min. diam. (in mms.)
Boulders		400
Stones	400	50
Gravel	50	2.54
Grit	2.54	0.85
Coarse sand	0.85	0.42
Sand	0.42	0.20
Fine sand	0.20	0.05 (?)
Mud	0.05 (?)	

Introduction to the Biological Part of the Survey.

The remainder of the investigation is divided into a consideration of:—

(1) The algae

(2) The burrowing animals

(3) The surface living animals.

In each case, only certain of the commoner species are dealt with since:—

(1) Uncommon species, or isolated records are of little significance in understanding the general ecology of the area.

(2) In the time available, only the larger species could be collected so that many small but common species were probably passed over.

(3) In view of the difficulty in identifying the species of the genus Gammarus, these were omitted from the survey.

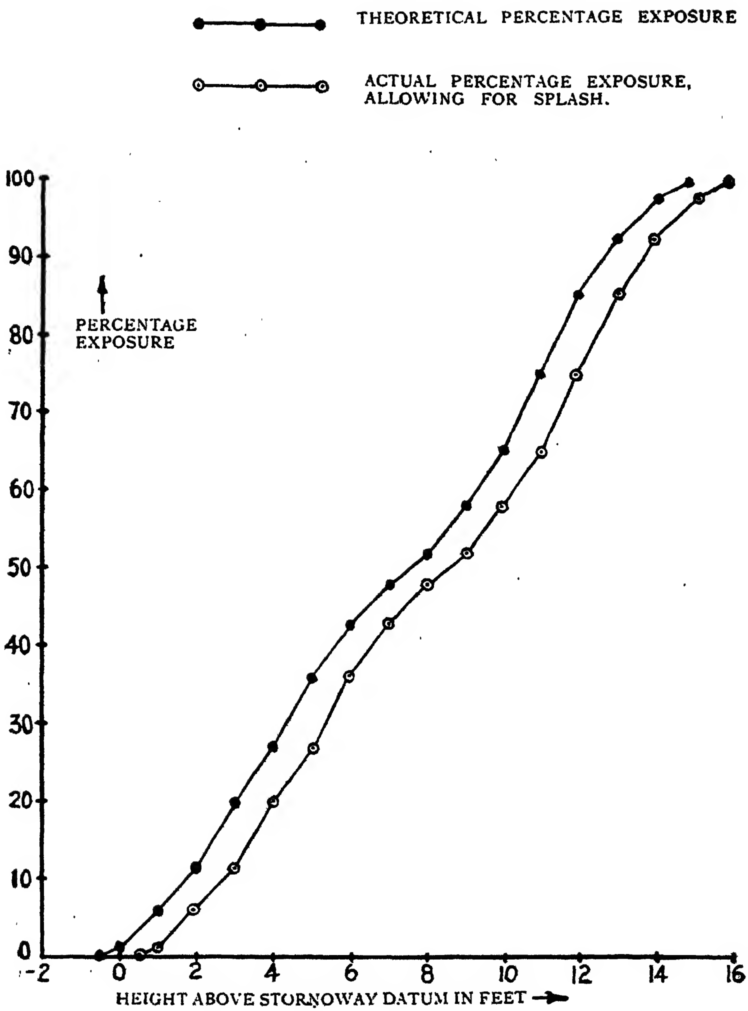


Figure 1.

Theoretical percentage exposure, and actual percentage exposure plotted against height in feet above the Stornoway datum.

Two areas of the beach formed comparatively specialised habitats, namely an Enteromorpha pool on the sloping sandstone rocks, and the bed of decaying seaweed at High Water Mark of the Spring tides. Since these situations cannot be conveniently compared with the rest of the beach, they are omitted from this study.

The general procedure was to collect the animals and plants at a given height on the beach, noting the environmental conditions at this height, and later attempting to correlate the two.

Since we can already correlate height with percentage exposure, the results are given directly in terms of the latter with reference to the individual species.

The Algae.

The distribution of the algae was rather difficult to determine exactly, since isolated specimens were often found some distance away from the main body in question. All these specimens were attached to small stones, and as they had probably been washed from some other part of the beach, their distribution is not recorded below.

Distribution of the dominant algae.

The above is recorded diagrammatically on Figure 2, where the results obtained on the West of the beach (boulder area) are compared with those from the East (sandstone rocks on the upper, and embedded stones on the lower part of the beach).

Figure 2 shows that the mid-points of the zones of the two uppermost algae *(Pelvetia canaliculata* and *Fucus spiralis)* are appreciably lower on the West, than on the East of the beach. Since greater splash would tend to wet a greater height above the water level, the opposite result might have been expected. Kitching (4), however, working on the Argyll coast, concludes that the algae in question are affected by wave action in two opposite ways. Firstly, increased splash tends to raise the zones by wetting a greater height above the water level; and secondly, too vigorous wave action results in mechanical shock, which tends to lower the zones. It does not seem likely that, on a sheltered type of coast such as the one at Raasay, mechanical shock would be great enough to lower the zones, but this is the only apparent explanation.

It will be noted that the Pelvetia and Ascophyllum zones are more extensive on the sheltered eastern side of the beach than on the western side, while the reverse is true of *F. spiralis*.

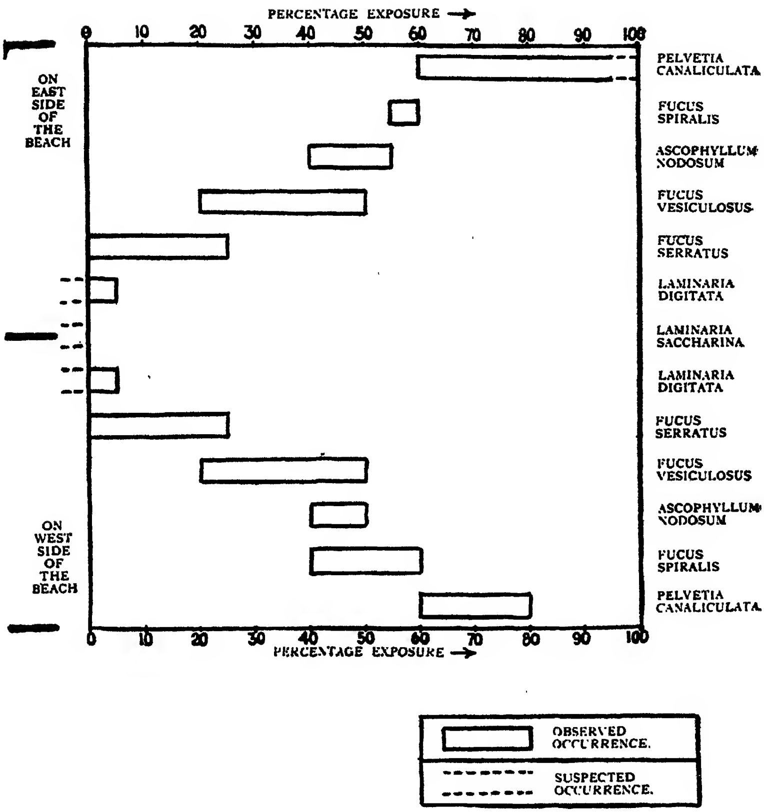


Figure 2.

The distribution of the dominant algae in terms of percentage exposure, the distribution of the species on the East side of the beach being compared with that on the West.

This may also be due to differences in the mechanical effect of wave action, since Cotton (2) thinks that Pelvetia and Ascophyllum are both more susceptible to " exposure " than *F. spiralis*.

Conclusions to be drawn from the consideration of the dominant species.

(1) There was a definite zonation of the dominant species, each species forming a fairly well defined and homogeneous zone. The only possible exception was *Ascophyllum nodosum*, which overlapped to a certain extent with *F. vesiculosus*, and to a lesser extent with *F. spiralis*.

(2) The zones occupied by different species were not at a constant level, nor of a constant breadth. This implies that if the distribution of an animal is dependent upon exposure to the atmosphere rather than on the distribution of the dominant algae, then it is unsatisfactory to describe its distribution in terms of that of the algae.

(3) The variation in the height and extent of the zones was most marked in the case of the three species highest up the beach, and this variation is largely explicable in terms of the mechanical shock of wave action.

Analysis of the distribution of Enteromorpha compressa.

This species did not, like those mentioned above, form a conspicuous zone over which it was the dominant form, but was scattered over wide areas of the beach in regions of from 70% to 5% exposure. In all these areas there was drainage of water left by the retreating tide, mixed with some fresh water, and it was concluded that the distribution of this species was correlated with lowered salinity.

The Burrowing Animals.

The burrowing animals were first of all collected by both digging and sifting, but since similar results were obtained by each of the methods, and as sifting took much longer to perform, it was discontinued.

Each digging was over approximately the same surface area, and at each, the numbers of familiar species were noted, while all unfamiliar or doubtful species were preserved for future identification. In each case notes were also made of the condition of the substratum.

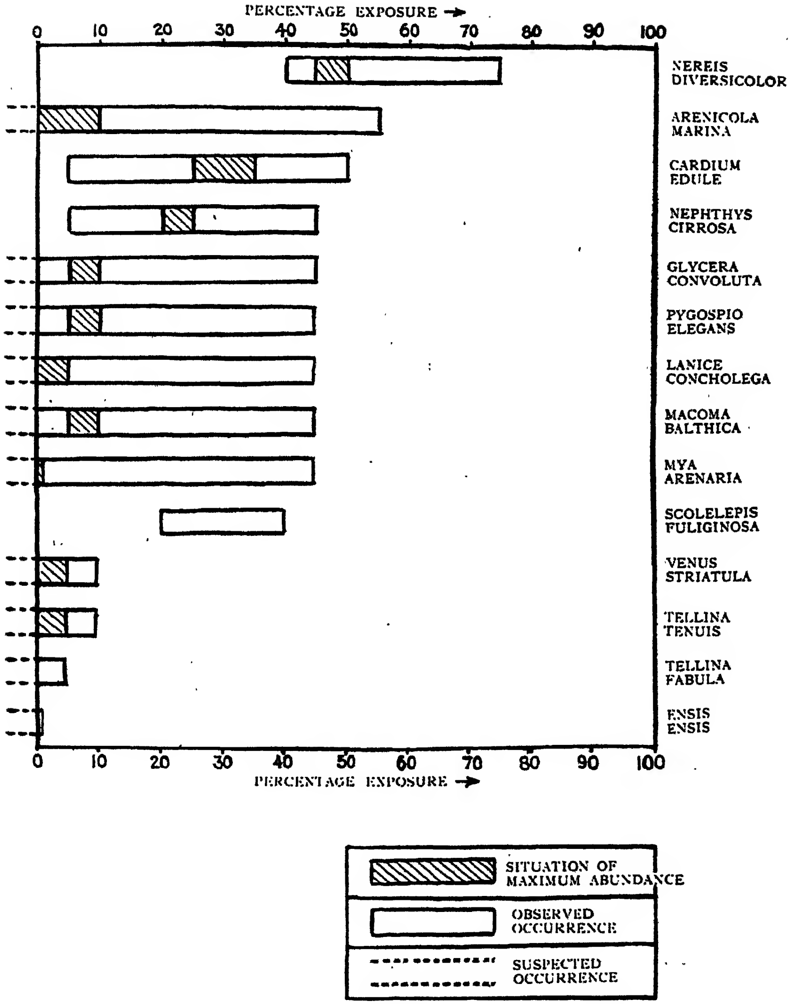


Figure 3.

The distribution of the burrowing animals in terms of percentage exposure.

Method of treatment of results.

The results obtained were not sufficiently detailed to allow accurate distribution curves to be drawn for each species. They showed in general, that each species was comparatively abundant over a small region of the beach, while there was a larger region over which it was comparatively rare. The limits of both regions were usually fairly well defined, and hence in the data which follows, the limits of the total distribution of the region of maximum abundance are both given. The latter are taken to be those levels at which there was the most pronounced increase or decrease in the abundance of the species.

In some species (e.g. *Scolelepis fuliginosa*) no such pronounced changes were observed, and so the boundaries of zone of maximum abundance are not specified.

The limits of distribution of the different species (arranged in order of their respective phyla) are given in Table 3, in terms of percentage exposure, together with the details of the condition of the substratum. In this table, the expression " 0% probably lower," means that the species was found at the line of 0% exposure, and there was reason to believe that it occurred below this line. The results are shown diagrammatically on Figure 3, where the distribution of the species is shown against a scale of percentage exposure.

Consideration of the limits of distribution.

Previous workers have only considered the upper and lower limits of general occurrence of a species in attempts to discover the existence of critical levels on a beach. In the present investigation, it is considered that, while the upper and lower limits of occurrence are undoubtedly of great significance, the upper and lower limits of the region of maximum abundance are at least equally important. Thus, in an attempt to discover the existence of critical levels on the beach, both types of limits are here considered together, and in Figure 4, the numbers of these limits are shown diagrammatically against a scale of percentage exposure. A diagrammatic method is adopted, since a graphical method might be misleading.

Of the above limits, all but one occur at the three levels below:—

(1) From 5% to 10% exposure (15 limits)

(2) About 20% exposure (4 limits)

(3) About 45% exposure (13 limits).

TABLE 3.

Species	Upper limit and conditions of the substratum	Position of maximum abundance and the conditions of the substratum	Lower limits and the condition of the substratum
Nereis diversicolor C. F. Muller	75% in an area with fresh water drainage, 60% elsewhere. In both cases in sandy mud.	50% to 45% in dirty gravel and grit.	40% in dirty gravel and grit.
Nepthys cirrosa Ehlers	45% in mixed gravel, grit, sand, and mud.	25% to 20% in clean sand.	5% in clean sand.
Glycera convoluta Keferstein	45% in fine sand and mud.	10% to 5% in sand and fine sand.	0% in sand and fine sand.
Scholelepsis fuliginosa (Claparède)	40% in gravel, grit, sand and mud.	Doubtful.	20% in grit, sand, and mud.
Pygospio elegans Claparède	45% in gritty sand with mud.	10% to 5% in sandy mud.	0% in clean sand.
Arenicola marina L.	55% in fine sand and mud.	10% to 0% in fine sand.	0% in clean sand, probably lower.
Lanice conchilega (Pallas)	45% in grit and sand.	5% to 0% in gritty sand.	0% in clean sand, probably lower.
Cardium edule L.	50% in gravel, grit, sand and mud.	35% to 25% sand and mud.	5% in clean sand.
Venus striatula (da Costa)	10% in grit sand and mud.	5% to 0% in clean sand.	0% in clean sand, probably lower.
Tellina tenuis da Costa	10% in grit, sand and mud.	5% to 0% in clean sand.	0% in clean sand, probably lower.
Tellina fabula Gmelin	5% in clean sand.	Doubtful.	0% in clean sand, probably lower.
Macoma balthica L.	45% in grit, sand and mud.	10% to 5% in fine muddy sand.	0% in clean sand,
Ensis ensis L.	Just above 0% in clean sand.	0% in clean sand.	0% in clean sand, probably lower.
Mya arenaria L	45% in gravel, grit, sand and mud.	Just above 0% to 0% in sand and fine sand.	0% in sand and fine sand.

On the above evidence, the level at 5% exposure is rather more critical than that at 45% exposure. Actually it was much more so, because between the line of 5% exposure and 0% exposure, many species were found which were found nowhere else on the beach. These species were not present in sufficiently large numbers to be included among the commoner species of the beach, and so they are not included in the above table. The species in question were *Echinocardium cordatum* (Pennant), *Cochlodesma praetenue* (Montagu), *Spisula subtruncata* (da Costa), *Gari fervensis* (Gmelin), *Thracia phaseolina* (Lamark), *Dosinia lupinus lincta* (Montagu), and *Phacoides borealis* (L.)

Possible explanations of the occurrence of the critical levels.

The term " critical level " is taken to mean a level at which there was a marked change in the fauna with respect to its species composition or the numbers of each species.

The existence of the critical levels on the shore might be due to any of the following possible factors:—

(1) Changes in the substratum.

(2) Changes in the slope of the beach.

(3) Changes in the inherent nature of the fauna.

(1) *Because of changes in the substratum.*

A change in the substratum occurred between the 5% and 10% exposure levels on the beach. Between these levels, the mixed substratum of gravel, grit, sand, and mud on the upper beach gave way to the predominantly sandy region of the lower beach. This change might account in part or in whole for the existence of a critical level at about 5% exposure level.

(2) *Because of changes in the slope of the beach.*

It is possible to find the slope of the beach as a series of averages between the adjacent contour lines, by dividing the differences in heights between the lines by the average horizontal distance between them. The average horizontal distance is best taken near the N.S. line bisecting the beach, since it was near this line that most of the records of burrowing animals were obtained. The slope of the beach at the height of the different contour lines is shown in column 13 of Table 1, intermediate figures being given in column 12.

On Figure 5, the slopes of the different parts of the beach are plotted against a scale of percentage exposure, the

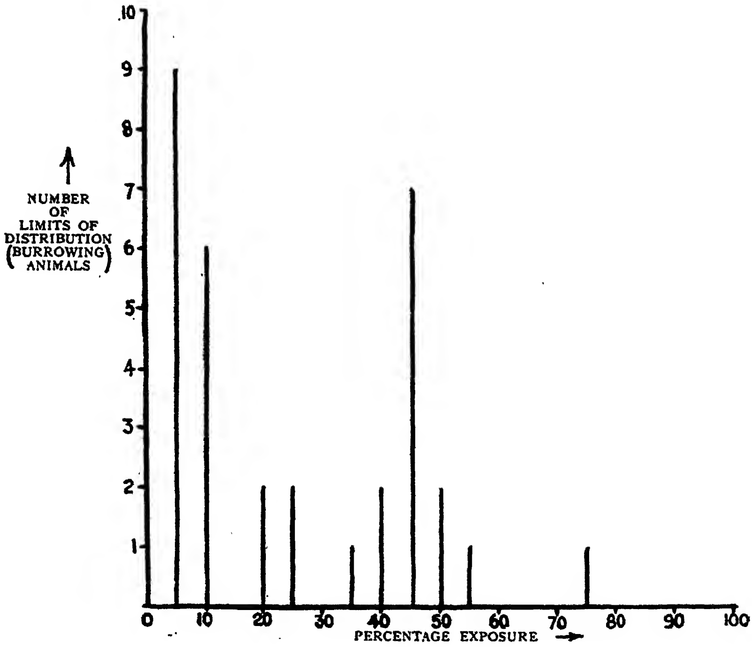


Figure 4.

Diagram showing the number of limits of distribution of the burrowing animals against a scale of percentage exposure.

average slope between adjacent lines being plotted on a percentage exposure midway between those corresponding to the lines. The figure shows that the slope is greatest on the upper part of the beach, and decreases regularly till at about the 45% exposure level, when the slope of the beach remains fairly constant. From about the 30% exposure level to about the 15% exposure level, the slope again increases, after which it falls and then rises again slightly at the 5% exposure level. When the slope of the beach increases, the drainage also increases, and therefore the substratum will be less suitable for supporting burrowing animals. Thus where the slope of the beach increases, a change in the fauna might be expected, from a type requiring a moist substratum, to one requiring a less moist substratum.

We might expect a change in the fauna at the following exposure levels:—

(1) 10% to 20%. An upper limit for species below this level.

(2) 15% to 30%. An upper limit for species below this level.

(3) 45% to 50%. An upper limit for species below this level.

A few upper limits did occur at about 10% exposure, a few lower limits at about 20% exposure, and many other limits at about 45% exposure. Thus the existence of the three critical levels may be explained in part by changes in the slope of the beach.

(3) *Because of changes in the inherent nature of the fauna.*

Summarising the above, it is possible to account for the existence of the critical levels, either wholly or partially, in terms of discontinuity in the physical environment. Thus the critical level at 5% to 10% exposure level can be partially explained in terms of a change in the substratum, and partially in terms of a change in the slope of the beach. Similarly the critical levels at about 20% exposure and 40% exposure levels respectively, may possibly be explained in terms of a change in the slope of the beach.

It is impossible, from the results of the present investigation, to say whether these physical changes serve as a complete explanation for the existence of these critical levels, but there is some evidence that this may be so. Thus many of the species have been recorded from much higher up the beach by other workers in areas of a more uniform substratum.

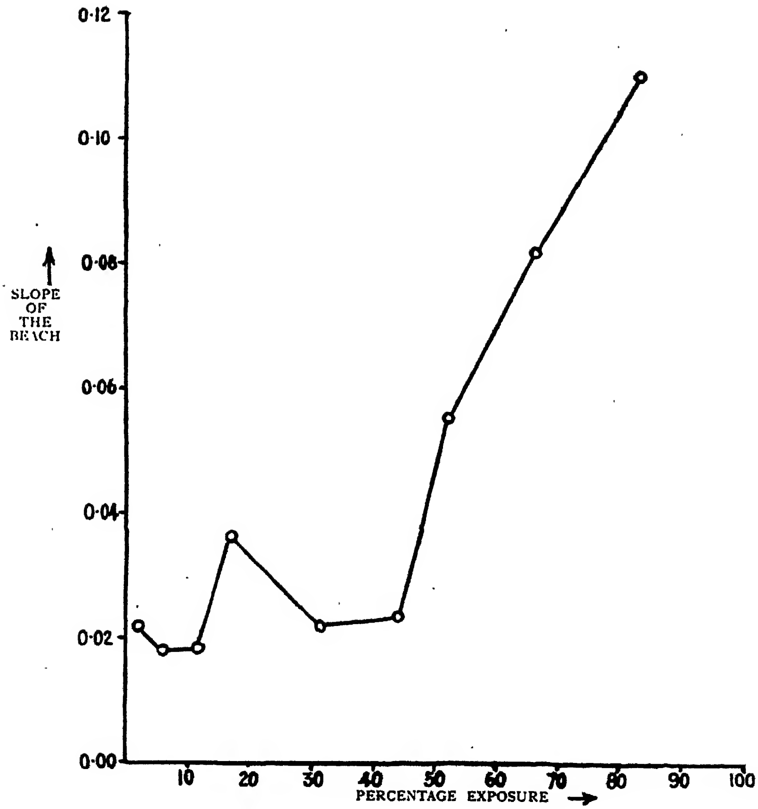


Figure 5.

The slope of the beach plotted against percentage exposure.

Thus, for example, Stephen (5) notes the occurrence of the *Tellina tenuis* at much higher levels upon the beach, at Kames Bay in a sandy substratum.

If, on the other hand, physical discontinuity is considered insufficient to explain the existence of the critical levels, we must conclude that the existence of the critical levels is due to change in the nature of the fauna itself.

One littoral burrowing animal might reasonably be adapted to live in a region of certain percentage exposure of the surface, better than another. The first animal should then replace the second at this exposure level. If one *group* of animal replaces another *group* at any level, we must conclude that the *group behaves as a unit* with respect to changes in percentage exposure of the surface.

It is possible, but not necessarily probable, that the littoral burrowing animals studied were divisible into two groups, each of which could best inhabit a certain stretch of the beach.

(a) The *"sub-littoral" species* which could best inhabit those parts of the beach where the surface exposure was less than about 5%.

(b) The *"intertidal" species* which could best inhabit those parts of the beach where the surface exposure was from 5% to 50%.

The Surface Living Animals.

Introduction.

The term "surface living animals" is here taken to include all animals living permanently on the beach, with exception of the burrowing forms. Collections were made over many parts of the beach, and records made of the species obtained, their comparative abundance, and any ecological factors thought to be of significance. As in the case of the burrowing species, the results are for the species considered individually, and are given directly in terms of percentage exposure. Since the collections were not extensive enough to give a clear indication of the situation of maximum abundance, only the upper and lower limits are given in the results below.

The results are expressed diagrammatically on Figure 6, where the distribution of the different species is shown against a scale of percentage exposure. The various types of situations in which the species were found is also shown on this figure, by means of different symbols to the right of the specific names.

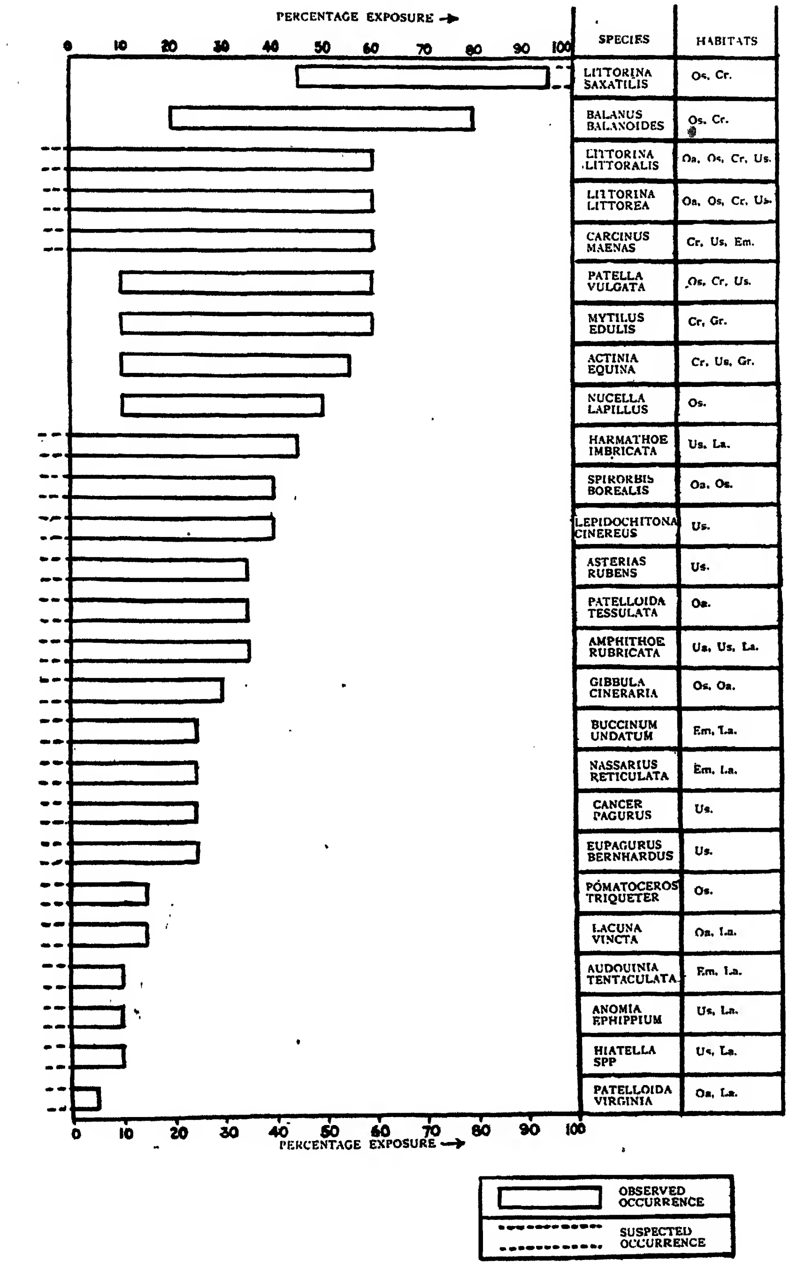


Figure 6.

Showing the distribution of the surface living animals in terms of percentage exposure, and also their habitats. The latter are indicated by the symbols to the right of the specific names, the following abbreviations being used :—Cr—in crevices, Em—embedded under stones, Gr—in gravel, La—in Laminaria holdfasts, Oa—on fronds of algae, Os—on stones, Ua—under fronds of algae, Us—under stones, When several symbols are given, that representing the situation most commonly inhabited by the species is given first, and vice versa.

Consideration of the limits of distribution.

(1) *Possible movement of the animals.*

The problem is much complicated by the fact that many of the animals were not sessile, but were free to move over the beach, so that the lines of demarcation of their distribution area could not be decided with certainty. This means that there may be great inaccuracies in the distribution of these species in terms of percentage exposure. The species in which the most pronounced movement was suspected included *Jaera marina, Ligia oceanica,* and *Orchestia gammarella,* and it was suspected that the distribution of these species was different at the Spring tides and the Neaps, and that during the neap tides they moved down the beach towards the level of high water neaps. Since there is this uncertainty with regard to their distribution, they are not represented on Figure 6.

It is also to be emphasised that a similar type of movement may occur in many more of the species dealt with above, so that the accuracy of the results may be much diminished. Thus in the discussion below, the analysis is only investigated to the nearest 10% percentage exposure.

(2) *Heterogeneity of the habitat.*

Another difficulty in analysing the results is that the species occurred in very different types of habitats. It was extremely rare to find even a single species in a completely uniform habitat, and most of the species had either their upper or lower limit in a different type of habitat from that in which they normally occurred. Thus *Littorina saxatilis* was normally found as a dweller on exposed surfaces of rock, but at its upper limit was only found in very sheltered situations, such as in crevices. Since 95% exposure probably means much more on an open face of rock than it does in a crevice, it is obvious that it is very difficult to discover the real significance of " percentage exposure." No attempt is made below to subdivide the habitat, since the results are not sufficiently detailed to allow this, and the habitat is considered as being completely homogeneous, although this was obviously not so.

(3) *Analysis of the numbers of limits of distribution.*

The results are considered in the same way as those concerning the burrowing animals, and in the same way the numbers of limits of distribution are shown diagrammatically

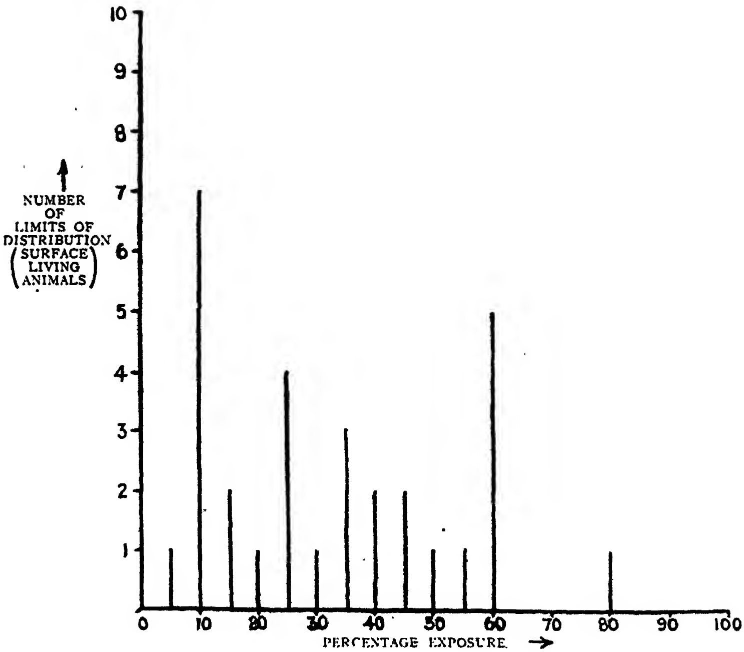


Figure 7.

Diagram showing the number of limits of distribution of the surface living animals against a scale of percentage exposure.

Figure 7 shows that there are two well marked maxima in the numbers of limits, at percentage exposures of 10% and 60% respectively. In addition there is a third, but less well defined maximum at about 25% exposure.

Thus it appears that there are three critical levels on the beach, corresponding to exposures of 10%, about 25%, and 60%.

Since there was great diversity in the habitat, and the types of animals found therein, the situation may be clarified by analysing the results of the upper and lower limits separately. Considering the upper and lower limits separately, these are distributed as below:—

Range of percentage exposure	Number of upper limits	Number of lower limits
Less than 0	Doubtful	Doubtful
0 to less than 10	1	0
10 ,, ,, ,, 20	5	4
20 ,, ,, ,, 30	4	1
30 ,, ,, ,, 40	4	0
40 ,, ,, ,, 50	3	1
50 ,, ,, ,, 60	2	0
60 ,, ,, ,, 70	5	0
70 ,, ,, ,, 80	1	0
80 ,, ,, ,, 90	1	0
Above 90	1	0

Thus of the three critical levels, the one at 10% to 20% exposure is due to the occurrence of both upper and lower limits, and the ones at 20% to 30%, and at 60% to 70% exposures are both due to the occurrence of upper limits at these levels.

The existence of critical levels on the shore might be due to any of the following possible factors:—

(1) Physical discontinuity.

(2) Changes in the algal zones.

(3) Changes in the inherent nature of the fauna.

(1) *Because of physical discontinuity.*

The critical level of 10% to 20% exposure was the lower limit of many animals characteristic of the boulder area, including *Mytilus edulis, Patella vulgata, Actinia equina,* ana *Nucella lapillus*. The occurrence of these lower limits at this level is probably explained by the fact that at this level the boulder area came to its lower limit (below which it was replaced by sand with a few embedded stones). Thus on adjacent beaches where the boulders extended further down, the above species were found at much lower levels.

Physical discontinuity also occurred at the same level of 60% exposure, corresponding to another of the critical levels, since here the sandstone rocks on the East of the beach came to their lower limit, and also the boulders on the West of the beach became too deeply embedded to afford shelter for the " under-stone " fauna. No species, however, had their lower limits on the sandstone rocks at 60% exposure, since all species found on the sandstone rocks were also found in the boulder regions where they could extend further down. In addition only one of the species of the " under-stone " fauna *(Carcinus maenas)* its upper limit at this level, so the existence of the 60% critical level cannot be explained in terms of physical discontinuity.

The same applies at the 25% critical level.

(2) *Because of changes in the algal zones.*

At the critical level corresponding to about 25% exposure, the dominant alga changed, and *Fucus vesiculosus* gave way to *F. serratus*. Only one species having any possible association with the algae at the level *(Lacuna vincta)* had a limit at 25% exposure, so the existence of this level cannot be explained on the basis of a change in the dominant alga.

At the critical level corresponding to 60% exposure, the dominant alga changed, and the *Pelvetia canaliculata* above this level approximately was replaced by *F. spiralis* below it. The only species having any possible association with the algae and having limits at this level were *Littorina littoralis* and *L. littorea,* so that change in the dominant alga would not entirely explain the existence of the 60% critical level.

The same applies to the 10% critical level.

(3) *Because of changes in the inherent nature of the fauna.*

Summarising the results of the above discussion, the 10% critical level can be explained to a large extent in terms of discontinuity in the physical conditions, and the 25% and

60% critical levels can only be partially explained in terms of a change in the dominant algae. The existence of these two critical levels is thus best explained on a basis of changes in the inherent nature of the fauna. The fauna could be grouped as below:—

(1) The "animals of the lower beach," which cannot ascend above the level corresponding to about 25% exposure.

(2) The "intertidal animals" which cannot ascend above the level corresponding to 60% exposure.

Comparison of the results obtained, with those of other workers.

It is significant to compare the results obtained above with those obtained by Colman (1) at Wembury. At the outset it should be pointed out that Colman was working only with the sessile animals and plants occurring on open surface of rock, and might therefore be expected to obtain clearer cut results than the survey above in which sessile and moving animals from a very heterogeneous environment are dealt with.

Colman deduced that there were three critical levels on the beach he studied, corresponding to exposures of 5%, 20% and 60%. These agree very closely with the results obtained above, in that critical levels were obtained corresponding to 10%, about 25%, and 60%; and moreover in the fact that the first of these three may be raised on the beach at Raasay, by the absence of a suitable environment lower down.

With respect to least critical levels, Colman demonstrated that the level of 40% exposure was the least critical at Wembury, while at Raasay this was not noticeably so, since seven of the limits occurred between 35% and 45% inclusive.

Fischer-Piette (3) also notes that at about 50% exposure there are very few upper limits of organisms on exposed rocks. At Raasay, on the other hand three upper limits occurred between 45% and 55% exposure (inclusive). The difference in the results may be explained by the fact that five of the eight upper limits occurring between 35% and 55% exposure (inclusive) were those of animals occurring under stones. Thus the levels themselves are referred to in terms of percentage exposure of the surface, but it is not easy to infer from this the conditions under stones. The "under stones" habitat itself is a very diverse one including situations comparable with crevices, rock pools, and those in which burrowing animals are found. Bearing this diversity in mind, it appears very unwise to infer conclusions with respect to the distribution of animals from "under stone" situations from a knowledge of the percentage exposure of the surface.

Summary.

1. A topographical survey was made of a beach on the Island of Raasay, Inner Hebrides, and the heights of the different parts of the beach were noted by means of contour lines.

2. These contour lines were calibrated with respect to percentage exposure by correlating observed measurements at Raasay with predicted records for the nearest available station (Stornoway), and making due allowance for splash. Thus by means of interpolation, the percentage exposure at any part of the beach was obtained.

(3) The main topographical features of the beach were noted as ecological factors of possible significance.

(4) The distribution of the dominant algae was determined, and, by reference to the contour lines, derived in terms of percentage exposure. A definite zonation of species was noted, but the zones did not occupy exactly the same ranges of percentage exposure on different parts of the beach. The difference in zones was most marked in cases of *Pelvetia canaliculata, Fucus spiralis*, and *Ascophyllum nodosum*, and is largely explicable in terms of the mechanical shock of wave action.

5. The distribution of the commoner burrowing animals was recorded in terms of percentage exposure, and the succession of species noted. Critical levels were observed at levels corresponding to exposures of 0%, 10%, 20%, and 50%, and the existence of these levels partially explained in terms of physical discontinuity. The suggestion is put forward that the burrowing animals may be divisible into groups, which are critically and similarly affected at the above levels.

6. The distribution of the commoner surface living animals was recorded in terms of percentage exposure, and the succession of species noted. Criticals levels were noted at the exposure levels of 10%, and about 25%, and 60%, the existence of the first only, being explicable in terms of physical discontinuity. The critical levels appear largely independent of changes in the dominant algae at different levels, and the tentative conclusion is put forward that the surface living animals are divisible into groups, which are critically and similarly affected at the above exposure levels.

7. The distribution of the surface living animals is compared with the results obtained by Colman (1) at Wembury, where critical levels were noted at 5%, 20% and 60% exposure

levels. At Raasay there was no region of the beach showing a marked absence of both upper and lower limits. This is probably due to the fact that animals living under stones, and not merely on their surfaces, are considered.

8. The diversity of the " under stone " habitat is emphasised, and the inadvisability of regarding a measurement of percentage exposure as a true indication of the condition in this environment, is pointed out.

Acknowledgement.

I am deeply indebted to Professor A. D. Hobson for his invaluable advice and encouragement, without which, this work could never have been prepared for publication.

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CONTENTS.

FURTHER OBSERVATIONS ON THE VASCULAR PLANTS OF THE OUTER HEBRIDES (V.-C. 110).

By

J. W. Heslop Harrison, F.R.S., Helena Heslop Harrison, M.Sc., W. A. Clark, B.Sc., Ph.D. and R. B. Cooke.

During the two summers which have elapsed since our Preliminary Flora of the Outer Hebrides (**Proc. Univ. Durham Phil. Soc. 10**, 228-273, 1941) went to press, various opportunities of extending our investigations have presented themselves, and these have been utilized to the full. As a result, we have not only added a series of important species to the flora of v.-c. 110, but have extended the known range of many other plants in the "Long Island" by discovering them on new islands and in new stations. These new observations, for obvious reasons, we consider it best to place on record at once.

Ranunculus trichophyllus Chaix.
This species, with its var. *Drouetii* F. Schultz, was noted quite commonly in many lochs on the Isles of North Uist and Baleshare.

R. Flammula var. **radicans** Nolte.
Tighary and Trumisgarry, North Uist, but in small quantity.

R. sceleratus L.
Sparsely around lochans on Baleshare.

Caltha radicans Forster.
Near Sponish Bridge, N. Uist.

Nuphar lutea Sibth. & Sm.
In a lochan, accompanied by *Nymphaea alba* L., near Loch Minish, N. Uist.

Fumaria officinalis L.
As the var. *minor* Koch to the north of Ard a Mhorain, N. Uist.

Nasturtium officinale R.Br.
Not rare on Baleshare and N. Uist.

Erophila verna L.
In the form of var. *cabillonensis* Jord. (O. E. Schultz) on the sand dunes, Daliburgh, S. Uist.

Cochlearia anglica L.
Not common near Lochmaddy, N. Uist.

Sisymbrium officinale L.
With the var. *leiocarpum* DC. near houses on N. Uist.

Viola Curtisii Forst. × **V. tricolor** L. (var. ?)
In newly broken ground near Goulaby Burn, N. Uist.

Minuartia peploides (L.) Hiern.
At several points on the east of Baleshare.

Sagina maritima G. Don.
Near Lochmaddy and Garry Gaal, N. Uist.

Spergularia rupicola Lobel.
Locally not rare near Loch Houram, N. Uist.

Hypericum elodes L.
Plentiful around and in a lochan on Baleshare; often in deeper water forming a long straggling tangle, and on the shore occurring with strange associates like *Carex limosa.* This forms a noteworthy extension of range.

Geranium dissectum L.
Near Tarbert, N. Harris (where it is biennial), Lochmaddy, N. Uist, and Lochboisdale, S. Uist.

Oxalis Acetosella L.
Not rare as described in the Preliminary Flora, but really abundant amongst bracken, under cliffs and along loch edges in many localities on N. and S. Uist.

Medicago lupulina L.
Not common; Lochmaddy, N. Uist and Lochboisdale, S. Uist.

Trifolium hybridum L.
On ground from which the turf had been removed, Lochmaddy, N. Uist.

Lotus uliginosus Schkuhr.
The variety *glabriuscula* Bab. occurred in plenty near Sponish Bridge, N. Uist; also Laxay, Lewis.

Vicia angustifolia L.
Very rare on machair land behind Hornish Strand, N. Uist.

Lathyrus pratensis L.
Common at many points on N. Uist and Baleshare: Sponish Bridge, Hosta, Sollas, Ard a Mhòrain, Newton etc.

Rubus incurvatus Bab.
Scattered on N. Uist, Loch Fada, Loch Minish etc.

R. polyanthemos Lindeb.
Only on the South Lee, N. Uist.

R. gratus Focke.
Cliffs on the North Lee and down to the coast, Crogary More, Sponish Harbour and Lochmaddy, N. Uist.

R. rhombifolius Weihe (non Rogers).
Only at Loch Eport, N. Uist.

R. mucronifer Sud.
Near the coast on lower slopes of North Lee, Sponish Harbour, and Lochmaddy, N. Uist.

Rosa canina L. (Agg.).
Of the Lutetianae group var. *oxyphylla* Rip. was collected in a ravine near the little bay, Bun an Uillt, S. Uist, and of the Dumales var. *dumalis* Bechst. was plentiful on rocks in many habitats on, and near, the North and South Lees, N. Uist.

R. glaucophylla Winch (Agg.).
The whole of the segregates reported for N. and S. Uist in our previous publications were collected in additional localities, whilst the form *jurassica* (Rouy) H.-H. was found on various rocky stations near the Lees etc., N. Uist.

R. mollis Sm. (Agg.).
The var. *typica* W.-Dod was detected near Lochmaddy, N. Uist.

R. Sherardi Dav. (Agg.).

Forms allied to, but quite distinct from, var. *glabrata* Ley have been collected on the South Lee, N. Uist and in Glen Noustapol, S. Uist. Further material is required for study before we can give a final judgement.

Saxifraga hypnoides L.

This is an extremely important addition to the flora of v.-c. 110 from the phytogeographical standpoint, as it was discovered in fair quantity, 50 feet below the summit, on the north face of Bheinn Mhor, S. Uist. The form agrees with none of the previously described segregates, least of all with those collected on the Isles of Rhum, Coll and Raasay. Examples are now growing alongside specimens brought from Coll and Rhum for study.

× **Drosera obovata** M. & K.

With the parents on the marshy ground Ard nam Madadh, N. Lee, N. Uist.

D. longifolia L.

Round Loch Minish, near Crogary More and Loch Langass, N. Uist.

Myriophyllum spicatum L.

Of fairly free occurrence on Baleshare and in lochs in the west of N. Uist.

Callitriche intermedia Hoffm.

In various lochans on Baleshare and at many points in N. Uist.

C. autumnalis L.

Plentiful in many of the lochans around Hougary, N. Uist.

Peplis Portula L.

In ditches near Lochmaddy and in a pond near Newton Lodge, N. Uist.

Epilobium angustifolium L.

Sea cliffs, N. Lee, N. Uist.

E. anagallidifolium Lam.

Careful comparisons of living Uisgnaval More plants with our puzzling Bheinn Mhor examples have convinced us that the latter are broad-leaved forms of the present species.

Cicuta virosa L.

A further station for this species on S. Uist is Loch Hallan.

Conopodium denudatum Koch.

Sponish Bridge, N. Uist.

Anthriscus sylvestris Hoffm.

Very rare in the same locality as the preceding.

Crithmum maritimum L.

Very rare on rocks on the south shore of West Loch Tarbert, S. Harris.

Oenanthe Lachenalii C.Gmel.

Very plentiful around the more westerly lochans on Baleshare and near Loch Grogary etc., N. Uist.

Ligusticum scoticum L.

We can now record this from the Tighary and North Lee areas of N. Uist.

Myrrhis Odorata Scop.

On a garden rubbish heap outside of Newton Lodge garden. We have examined this ground carefully and, in our opinion, the

plants forming the basis of N. Uist records of this, and other species like *Centaurea Scabiosa*, *Symphytum officinale*, *Allium ursinum* etc., made recently by other workers, should be treated for what they really are — garden outcasts!

Lonicera Periclymenum L.
Well-marked forms of var. *quercifolia* Aiton were collected on the South Lee, N. Uist.

Galium verum L.
Away from the machair, on cliffs and rock ledges south east of Truirebheinn, S. Uist.

G. palustre L.
The var. *Witheringii* Sm. was collected on the south shore of Loch Maddy, N. Uist.

Aster Tripolium L.
As the var. *arcticus* Th. Fr. not rare on Baleshare, and various points near Ahmore Strand and Sollas, N. Uist.

Antennaria dioica Gaertn.
Recorded now as occurring, with one or two other subalpine plants, on the flat sandy Isle of Baleshare.

Gnaphalium uliginosum L.
Locally plentiful near Grenetote, N. Uist.

Inula Helenium L.
As usual, near habitations, Baleshare.

Chrysanthemum Leucanthemum L.
Near Lochmaddy, N. Uist.

Tussilago Farfara L.
Along the burn draining Loch Hosta, N. Uist, toward the sea.

Petasites ovatus Hill.
In the same area, near Balmartin, N. Uist.

Crepis capillaris Wallr.
Near Lochmaddy, N. Uist.

Hieracium anglicum Fr.
As var. *acutifolium* Backh., Sron an Toister, Allt Tomnaval, West Loch Tarbert, N. Harris; and var. *cerintheforme* Backh. in Beesdale and on cliffs, W. Loch Tarbert, S. Harris.

H. iricum Fr.
Widely spread and common on rock ledges in N. and S. Harris.

H. flocculosum Backh.
On Truire Bheinn, S. Uist.

H. Boswelli Linton.
Creag an Eon, Beesdale, S. Harris; Oreval, N. Harris; Isle of Sandray.

H. argenteum Fr.
Molinginish, Laxadale, N. Harris; Strone Gunisdale, Beesdale, W. Loch Tarbert, S. Harris.

H. vulgatum Fr.
On the Lees, N. Uist.

H. orarium Lindeb.
Allt Maaruig, N. Harris; Crogary More, N. Uist; Allt Volagir, S. Uist.

H. scarpicum Pugsl.
Uig, Lewis; cliffs and dunes, Little Bernera, (Lewis).

H. ebudicum Pugsl.
Allt Trollamarig, N. Harris.

H. hebridense Pugsl.
Glen Valtos, Lewis; and widely spread, and not uncommon, on cliffs in N. and S. Harris.

H. Beebyanum Pugsl.
Glen Valtos, and Uig, Lewis; Isle of Berneray (Harris); not uncommon, N. Harris; Cnoc na Cloiche, S. Harris; Isle of Barra

H. uisticolum Pugsl.
Plentiful on the Lees and in the gorge between N. and S. Lee, N. Uist.

H. vennicontium Pugsl.
Lingadale, N. Harris.

H. aurantiacum NP.
In a " lazy bed " near Sponish; clearly an escape, but whence we could not discover.

Campanula rotundifolia L.
With the var. *speciosa* More, far from uncommon on machair and dune, N. Uist.

Arctostaphylos Uva-ursi Spreng.
On the cliff on the north bank of the stream entering the sea near An t-Aigeach, North Uist; at this point the stream makes a small wooded gorge.

Centunculus minimus L.
Near Loch Minish in the east, and Loch Grogary in the west, N. Uist.

Samolus Valerandi L.
On muddy ground to the north of Loch Grogary, N. Uist.

Lycopsis arvensis L.
Frequent in cornfields, Baleshare and N. Uist.

Myosotis palustris Hill.
Very beautiful plants at the head of Loch Grogary, N. Uist.

Lithospermum arvense L.
On the Machair Leathann, N. Uist, but rare.

Veronica persica Poir.
New to South Uist; not rare near Lochboisdale.

V. Chamaedrys L.
Sparingly near Lochmaddy and on Loch Eport, N. Uist.

V. anagallis-aquatica L.
Well distributed; with the var. *anagalliformis* Bor. on Baleshare and also on N. Uist.

V. scutellata L.
Marshes on Baleshare and around lochs on N. Uist.

Euphrasia micrantha Reichb.
Well distributed; Glen Skeaudale, Coire Serein, Trollamul, Loch Scourst, Allt Tomnaval, Laxadale Burn, Trollamarig, N. Harris; Kendibig, Seilebost, Loch nan Caor, S. Harris; Isle of Scotasay; South Lee, Trumisgarry, North Uist: f. *simplex* Pugsl., Molinginish, Whaling Station, Laxadale, Glen Skeaudale, N. Harris; Borve, Roneval, S. Harris; South Lee, N. Uist.

E. scotica Wetts.
Isle of Scarp; Lower cliffs, Oreval, saddle between Clisham and Tomnaval, N. Harris; South Lee, N. Uist: var. *purpurascens* Pugsl. Allt Maaruig, Allt Trollamarig, Glen Laxadale,

Allt Tomnaval, cliffs on north face of Toddun, Clisham above col, Oreval, Uisgnaval More, N. Harris; Rodel, Loch Diroclett, S. Harris; South Lee, N. Uist.

E. arctica Lange.
Lingadale, N. Harris: var. *laxa* Pugsl., Clisham (at 2000 feet), Uisgnaval More, N. Harris.

E. foulaensis Towns. ex Wettst.
Isle of Scarp; Allt Tomnaval, N. Harris.

E. curta Fr. ex Wettst.
As var. *Ostenfeldii* Pugsl. Isle of Scotasay; cliffs on Toddun, N. Harris: as var. *piccola* Pugsl., Roneval, S. Harris.

E. occidentalis Wetts.
Bealach Yeoravat, Borve, S. Harris; var. *calvescens* Pugsl., Isle of Scarp; Rudha Dubh, Tighary, N. Uist.

E. nemorosa Lohr.
Isle of Scarp; Lingadale, N. Harris; Luskentyre, S. Harris: var. *collina* Pugsl., Oban, N. Harris; Abhainn Gillan Tailleir, S. Harris: var. *transiens*, Isle of Scarp.

E. confusa Pugsl.
As var. *albida*, Isle of Scarp; Husinish, Allt Garbh, N. Harris; Seilebost, Kendibig, Borve, Scarastavore, S. Harris; Lochmaddy, Loch Scarie, Grenetote, Traigh Udal, N. Uist: as var. *grandiflora* Pugsl., Maaruig, N. Harris; Ardvey, S. Harris.

E. borealis Towns.
Slopes behind the sand-dunes, Luskentyre, S. Harris.

E. brevipila Burn. & Greml.
Lingarabay, S. Harris; Urgha, N. Harris; Loch Diroclett, S. Harris; Lochmaddy, N. Uist: as f. *subeglandulosa*, Urgha, Urgha Beg, Maaruig, N. Harris; Rodel, S. Harris; Isle of Baleshare; Ahmore Strand, N. Uist.

Hybrids:—

(1) **E. confusa** × **nemorosa,** Scarastavore, S. Harris.
(2) **E. confusa** × **micrantha,** Strone Scourst, N. Harris, Glen Horgabost, S. Harris.
(3) **E. confusa** f. **albida** × **micrantha,** Seilebost, Glen Horgabost, S. Harris; opposite Eilean Mhorain, N. Uist.
(4) **E. confusa** var. **albida** × **scotica,** Loch Stioclett, S. Harris.
(5) **E. confusa** var. **grandiflora** × **micrantha,** Loch Meavag, S. Harris.
(6) **E. micrantha** × **scotica,** var. **purpurascens,** Glen Trollamarig, N. Harris.
(7) **E. micrantha** × **scotica,** Oreval, N. Harris.
(8) **E. brevipila** × **confusa,** Isle of Scotasay; Tarbert, N. Harris.
(9) **E. brevipila** f. **subeglandulosa** × **curta,** Maaruig, N. Harris.
(10) **E. brevipila** × **micrantha,** Garry Gaal, N. Uist.
(11) **E. brevipila** × **nemorosa,** Loch Eport, Tighary. N. Uist.
(12) **E. brevipila** × **nemorosa** var. **collina,** Clachan, N. Uist.

Rhinanthus minor Ehr.
In the Tighary, Newton, Trumisgarry, Sollas areas, N. Uist.

Utricularia vulgaris L.
In lochans and streams on Baleshare.

U. intermedia Hayne.
On Baleshare and from Loch Minish to the Tighary district, N. Uist; of sporadic occurrence.

U. minor L.
Of much the same distribution as its congener *U. intermedia.*

Mentha arvensis L.
As a weed near Lochmaddy, N. Uist.

Thymus pycnotrichus Uecht.
On the Machair Leatham and Ard a Mhòrain, N. Uist.

T. zetlandicus Ronn. & Dr.
On the Ard a Mhòrain, N. Uist.

Scutellaria minor L.
Near Loch Skealtar, North Lee, Ben Langlass, Loch na Creige, N. Uist.

S. galericulata L.
Abundant on the shore where the stream from the gap between the North and South Lees reaches the sea.

× **Stachys ambigua** Sm. (=**S. palustris** × **S. sylvatica**).
We confess to a feeling of uneasiness about this plant which crops up, often commonly, in the Inner and Outer Hebrides; is it possible that a third and genuine species exists in the British Isles? It occurred near Lochmaddy, N. Uist.

Lamium amplexicaule L., **L. hybridum** Vill. and **L. mollucellifolium** Fr.
All three occur as garden weeds near Lochmaddy, N. Uist.

Ajuga pyramidalis L.
In the same gorge, to the south of the North Lee, as *Arctostaphylos Uva-ursi;* N. Uist.

Littorella uniflora Aschers.
Now recorded from Baleshare.

Suaeda maritima Dum.
Common on the east coast of Baleshare; also local in the west of N. Uist.

Salsola Kali L.
On the sands near Manish Point, N. Uist.

Polygonum aequale Lindm.; **P. heterophyllum** Lindm.
Both of these are widely dispersed over waste and cultivated ground on Baleshare and N. Uist.

P. Convolvulus L.
Not common as a weed in cornfields on N. Uist.

P. viviparum L.
On Beinn Mhor, S. Uist, in a much more typical guise than N. Harris specimens.

P. Bistorta L.
Amongst grass near Lochboisdale, S. Uist.

Corylus Avellana L.
As well grown shrubs in the same ravine as *Ajuga pyramidalis*, N. Uist.

Salix atrocinerea Brot.
One plant only on a lochan between Lochs Minish and Houram, N. Uist.

× **S. varia** H.-Harr. (**S. atrocinerea** × **S. aurita**).
Near the preceding.

S. herbacea L.
Found on North Lee, South Lee, Crogary More and Eaval, N. Uist.

Empetrum nigrum L.
Strangely enough to be found on Baleshare.

Orchis latifolia L. × **O. purpurella** Steph.
Near Trumisgarry, N. Uist; recorded only from Fuday previously.

O. occidentalis (Pugsl.) Willm.
Near Daliburgh, S. Uist, and by the roadside Clachan, N. Uist.

O. occidentalis (Pugsl.) Willm. × **O. purpurella** Steph.
Near Clachan, N. Uist.

O. Fuchsii Dr. var. **hebridensis** (Willm.) H.-Harr.
Scattered and not plentiful in transition zones on N. Uist.

Coeloglossum viride Hartm.
On dune and machair, Baleshare and S. Uist.

Coeloglossum viride Hartm. × **O. Fuchsii** var. **hebridensis** H.-Harr.
A single specimen on moorlands near Loch Scadavay, N. Uist.

Juncus effusus L.
Rare near Lochmaddy, N. Uist.

Luzula campestris L.
Now recorded for Baleshare.

Sparganium neglectum Beeby.
In lochs in the north east of N. Uist.

S. ramosum Curt.
Near the small runner at the head of Loch Grogary, N. Uist.

Lemna minor L.
Loch Mor etc., Baleshare; various sandy lochs in the west of N. Uist; Loch Hallan, S. Uist.

Baldellia ranunculoides (L.) Parl.
At various points near Sollas and Balmartin, N. Uist.

Triglochin palustre L.
Not uncommon on Baleshare.

Potamogeton* **gramineus** L., **P. filiformis** Pers., **P. pectinatus** L. × **P. suecicus** Richt.; × **P. nitens** Weber.
All found in Loch Hallan, S. Uist (Det. J.W.H.H.)

× **P. Cooperi** Fryer (=**P. crispus** L. × **P. perfoliatus** L.)
In a runner leading from a lochan near Ormaclett, S. Uist; new to the Outer Isles. (Det. J.W.H.H))

[**P. Millardii,** nom. nov. P. *pusillus* Hagström: Critical Researches, Kungl. Svensk. Vetenskapsakad. Handl., Ny. Foljd, LV, 121 (1916); Fernald, Linear-leaved North American Species of Potamogeton, Mem. Gray Herb, III, 60 (1932); *P. Berchtoldii* Dandy and Taylor, Studies of British Potamogetons — XIII, J. Bot. London XXVIII, 49 (1940). The doubts we expressed (Vasculum XXVII, 1942) in respect to the use of the names "*P. pusillus*" and "*P. Berchtoldii*" by Dandy and Taylor seem in our opinion to be justified, at least as far as "*P. Berchtoldii*" is concerned. In selecting the latter name for the species with open stipular sheaths, they have disregarded what we consider a very pertinent statement by

*The Potamagetons from North Uist and Baleshare, on account of their importance, are being discussed in a separate paper by Dr. W. A. Clark.

Hagström (l.c. 121-122) "Of *P. Berchtoldii* I have seen specimens from the very *locus classicus* 'Landskron Bohemia' determined by Fieber himself.—(They) are not at all a *pusillus* form, but very obviously and surely *mucronatus* x *pusillus*." (The "*pusillus*" here is of course, the *Berchtoldii* of Dandy and Taylor). Accepting these determinations of Fieber and Hagström as correct (and who is better fitted than the two for forming such judgments?), we leave the pure species itself without a name. To remedy this, we propose the name *P. Millardii* in recognition of the limnological researches of the late Dr. B. Millard Griffiths. J.W.H.H.]

P. Millardii Heslop Harrison.

In practically every loch and lochan on the machair from Berneray (Harris) to Barra. Material of this species from Loch Kildonan, South Uist, was lent in 1940 to Dandy and Taylor for study. They returned it as *P. pusillus* — a determination quite impossible of acceptance, for the plants concerned have open stipular sheaths. *P. pusillus* does occur in Loch Kildonan, but no specimens from that loch were amongst the material borrowed from us. We think it best to draw attention to this incorrect determination* by Dandy and Taylor now in case they should publish it later.

Ruppia spiralis Hartm.

Abundant in one of the western lochans on Baleshare.

Zostera marina L.

Common in Loch Blashaval and in the detached portion on the west side of the road near Alioter, N. Uist.

Naias flexilis Rostk. & Schmidt.

Very plentiftul in Loch Grogary and less so in Loch nam Margalan, North Uist — an extension of its known range in v.-c. 110.

Scirpus setaceus L.

Near Loch Houram, N. Uist.

S. lacustris L.

In Loch Nighe, below N. Lee, N. Uist.

S. Tabernaemontani Gmel.

Abundant in a small lochan on Baleshare and in Loch an Duin, N. Uist.

Blysmus rufus Link.

On Baleshare and the adjoining shores of N. Uist.

Eriophorum vaginatum L.; **E. angustifolium** Roth.

Both occur on Baleshare.

Carex Halleri Gunn.

Rare on Bheinn Mhor, S. Uist and on South Lee, N. Uist.

C. extensa Good.

Near Loch Houram, N. Uist.

*Here it seems best to point out that the tangle from Loch Fada, Colonsay, so smugly dismissed by Dandy and Taylor (*J. Bot.* Lond. 80, p. 22), as *Scirpus fluitans* (!!), contains a far from negligible percentage of *P. Millardii*! Moreover, these are not the only cases in which such corrections of their pronouncements are necessary.

C. limosa L.
Around a lochan on Baleshare, not rare; abundant in nearly every spongy bog between Bheinn Mhor and Lochboisdale, S. Uist.

C. lasiocarpa Ehrh.
Lochan north of Crogary Beg, N. Uist.

Phalaris arundinacea L.
As the var. *picta* in the alder thicket on the Goulaby Burn, N. Uist; almost certainly a garden escape.

Phleum pratense L.
Occasional near Lochmaddy and elsewhere on N. Uist; Lochboisdale, S. Uist.

Calamagrostis epigeios Roth.
Low on the eastern slopes of Truirebheinn, S. Uist; new to v.-c. 110.

Dactylis glomerata L.
Commoner than our previous records would indicate near Lochboisdale, S. Uist; also here and there on N. Uist.

Deschampsia setacea Richt.
In several stations on the margin of Loch Scadavay, N. Uist.

Festuca longifolia Thuill.
A very beautiful plant, referred with some doubt to this species by Dr. W. O. Howarth, was discovered on the Allt Volagir, S. Uist. The plant is really very puzzling and like no other British species.

F. ovina L.
The non-proliferated form of the var. *genuina* Gren. & Godr. was found on the Isle of Baleshare.

Phyllitis Scolopendrium L.
A single plant on a sea cliff above the Bun an Uillt, S. Uist.

Dryopteris Oreopteris Max.
On the Lees, N. Uist.

Botrychium Lunaria Sw.
Found on grassy slopes on Baleshare.

Equisetum sylvaticum L.
Very rare in the gap between North Lee and South Lee, N. Uist.

[We have much pleasure in thanking, as usual, Mr. H. W. Pugsley for his help with the Fumariae, Hieracia and Ephrasiae and Mr. W. Watson for dealing with our Rubi].

PONDWEEDS FROM NORTH UIST (V.-C 110), WITH A SPECIAL CONSIDERATION OF POTAMOGETON RUTILUS WOLFG. AND A NEW HYBRID.[1]

By W. A. CLARK, B.Sc., Ph.D.

(Dept. of Botany, King's College, Newcastle upon Tyne.)

In recent years many rare and interesting Potamogetons have been recorded from the Hebrides by the King's College Expeditions which have worked these islands. To extend, if possible, our list of discoveries, a short visit was made to North Uist last summer, and once again most striking results were obtained, an account of which is given in this paper. The two most interesting of the species collected were *Potamogeton rutilus* Wolfg., which previously had been recorded only from the Shetlands in the British Isles, and a new triple hybrid with the parentage (*P. gramineus* L. ×*P. perfoliatus* L.) ×*P. Millardii* Heslop Harrison; in other words the hybrid results from a crossing of ×*P. nitens* Weber and *P. Millardii* (=*P. Berchtoldii* Dandy & Taylor non Fieber).

Potamogeton natans L. Common in moorland and machair lochs; Lochs Grogary, Scarie and Magarlan, Loch an Strumore, Loch na Morgha, Loch na Hostrach, lochan between the Lees, N. Uist, and lochans on Baleshare.

P. polygonifolius Pourr. Plentiful in moorland lochs, drainage lodes, ditches, and streamlets, etc.; Goulaby Burn, streamlet between the Lees, Loch Scadavay, stream running from Loch Hosta, lochans between Ben Langass and Loch Scadavay, and lochans and ditches on Baleshare.

P. coloratus Hornem. Collected during a visit to the adjacent Monach Islands in July 1938 in Loch Sniogravat, where it occurs in some quantity. This record provides the most northerly station for this species in the British Isles.

P. gramineus L. Only recorded from the machair lochs where it is not uncommon; Lochs Grogary, Scarie, and Magarlan, Loch na Morgha and Loch Mhor, Baleshare.

×**P. nitens** Weber. Forms referable to this hybrid were collected in Lochs Grogary and Scarie, and Loch Mohr, Baleshare.

×**P. Heslop-Harrisonii** n. hybr. = (**P. gramineus** L. × **P. perfoliatus** L.) × **P. Millardii** Heslop Harrison.

Folia subacuta, sublanceolata, latitudinem maximum super medium praestantia, basi attenuata, caulina 2.5-4 cm. longa, 2-4 mm. lata, nervatura fere intermedia; simulate sterilis. Ceterum in habitu et in omnibus fere partibus etiam in anatomia caulis planta medium inter parentes tenens.

Type in the collection of the Dept. of Botany, King's College, Newcastle upon Tyne.

The stem slender and filiform, terete, the internodes shorter than the subtending leaves, apparently unbranched but with fascicles of young linear leaves in the axils of the main stem leaves. The leaves all submerged, sessile, alternate, olive green in colour; linear to linear-lanceolate, 2.5-4 cm. long, 2-4 mm. broad, tapering gradually to the base and more suddenly to the sub-acute apex; occasionally faintly cuspidate, margins crisped with rudimentary denticulations; 3-7 veined, with elongated nerve spaces, the principal lateral veins gradually joining the midrib, sometimes at the apex,

[1] I must express my gratitude to the King's College Research Committee for the grant which made this research possible.

sometimes shortly below, with a prominent chain-like network on either side of the midrib. Stipules open and convolute, short, scarious, blunt, many nerved but weakly so, the lower soon withering. Plant apparently sterile.

Habitat: Loch Grogary, North Uist, Outer Hebrides.

In a preliminary note in the Vasculum, Vol. 27, p. 20, the parentage of this hybrid was given as *P. gramineus* L. ×*P. Berchtoldii* Dandy & Taylor non Fieber, but after further investigation it now appears more likely that ×*P. nitens* Weber is the form concerned and not *P. gramineus* L.

Our material consists of four sterile shoots collected in Loch Grogary by Professor Heslop Harrison after whom the new hybrid is named. One of the plants is more highly developed than the others, but, apart from this, all agree amongst themselves. We hope to obtain other specimens to grow under observation and thus determine whether or not it fruits under favourable conditions.

That one of the parents must be a " pusilloid " species is immediately obvious from the narrow, in some cases almost linear, basal leaves, 2mm. in width, and from the filiform stem of the hybrid. Furthermore, the young leaves of the axillary fascicles are always three-nerved and linear, characters typical of the leaves of " pusilloid " species. As the stem is terete, this would seem to indicate that *P. rutilus* which is also present in Loch Grogary, and *P. Friesii*, found on the neighbouring island of Baleshare, are not involved in the cross as both possess strongly compressed stems. Our choice of " pusilloid " parent is thus restricted to *P. pusillus* L. and *P. Millardii* Heslop Harrison (=*P. Berchtoldii* Dandy & Taylor non Fieber), the only other available species in the Outer Hebrides.

The deep olive green colour of the leaves of the hybrid, the neuration of the rather rounded and faintly apiculate apices of the leaves of the axillary fascicles, and the two prominent bands of chain-like areolations on either side of the midrib of the older leaves, all point to *P. Millardii*. In my opinion, however, the open convolute nature of the stipular sheaths of ×*P. Heslop-Harrisonii* clinches the argument in favour of *P. Millardii* with which species as well as with ×*P. nitens*, the hybrid agrees in this respect. On the other hand, the sheaths of *P. pusillus* are closed and tubular; thus in a cross involving this species and ×*P. nitens*, the stipules might reasonably be expected to show at least some traces of this condition. In our hybrid, a careful examination of the stipules failed to reveal any signs of fusion even at the base and there seems, therefore, little doubt that *P. Millardii* is the " pusilloid " species concerned.

While the influence of *P. Millardii* on the hybrid is readily seen, the identity of the second parent is not so easily established. The submerged seven-nerved leaves of ×*P. Heslop-Harrisonii* indicate a parent with many nerved submerged leaves, and the following fulfilling this condition have been recorded from North Uist, *P. natans*, *P. polygonifolius*, *P. gramineus*, ×*P. nitens*, and *P. perfoliatus*. *P. coloratus*, though not found on North Uist, was collected on the adjacent Monach Islands. Of these species, the first two can be eliminated on the grounds that the leaves of the hybrid are both sessile and relatively short with a maximum length of 4 cm. The venation and texture of the leaves are also against these two species. Had *P. coloratus* been present in Loch Grogary, then it would have been necessary to consider it further as a possible parent, but, here again, it would be difficult to account for the sessile nature of the leaves of our plant. As the linear-lanceolate leaves of the hybrid show no signs of the clasping

leaf base and the hooded apex characteristic of those of *P. perfoliatus*, it would appear that this species is not directly involved in the cross. The remaining two plants, *P. gramineus* and ×*P. nitens*, both in the shape of their leaves and habit, closely resemble those of the hybrid. In all three, the leaves are sessile and linear-lanceolate with crisped denticulate margins, although in the hybrid the denticulation is of a very rudimentary character, and often wanting altogether.

To decide between these two plants is no easy matter, and the fact that ×*P. nitens* is itself a hybrid involving *P. gramineus* as one of the parents further complicates the problem. I think, however, that the shape and neuration of the apices of the main stem leaves and the nature of the stipules of the hybrid force a decision in favour of ×*P. nitens*.

The leaf apices of ×*P. Heslop-Harrisonii* are sub-acute, with a tendency to become more rounded and even faintly cuspidate. Now in *P. gramineus* the leaf apex is sharp and cuspidate; and in *P. Millardii* although the apices are, as a rule, more rounded, they are usually mucronate. It is, therefore, difficult to see how a cross involving these two species could produce the sub-acute apex characteristic of the leaves of the hybrid. No such difficulty arises, however, if ×*P. nitens* is the other parent, for, as a result of the influence of *P. perfoliatus*, the leaf apices of the former tend to be more obtuse, and even when cuspidate, are considerably broader than those of *P. gramineus*. This view is strengthened by a consideration of the neuration of the leaf apices of the hybrid. The principal lateral veins in this plant join the midrib gradually either at, or slightly below, the apex, and while these two conditions are met with in ×*P. nitens* only the former occurs in *P. gramineus*. The influence of *P. Millardii* on the neuration of the main stem leaves is chiefly seen in the elongated nerve spaces, although the possibility must be borne in mind that they may be due to the influence of *P. perfoliatus* acting through ×*P. nitens*. In the linear leaves of the axilliary fascicles, however, the neuration in all respects is the same as in *P. Millardii*.

Before leaving the subject of leaf shape, it must be pointed out that the main stem leaves of our hybrid resemble closely the submerged leaves of ×*P. lanceolatus* Smith (=*P. alpinus* ×*P. Millardii*). The latter, however, are of a much lighter green colour, and the apical neuration, inherited from *P. alpinus*, is likewise quite distinct.

Reference has already been made to the open convolute nature of the stipules as providing evidence in favour of *P. Millardii*. Their brown scarious nature, and their blunt apices, together with the many faint nerves could, however, only have been derived from *P. perfoliatus* through ×*P. nitens*.

Lastly, the habit of the hybrid would seem to approach nearer to ×*P. nitens* than to *P. gramineus*, although the differences between these two are slight. The unbranched stem of the hybrid and the short internodes at the tops of the branches, so that the upper leaves tend to overlap, are significant characters to note in this connection.

Taking everything into account, therefore, it would appear that most characters of the hybrid can best be accounted for on the assumption that it has the parentage (*P. gramineus* ×*P. perfoliatus*) ×*P. Millardii*.

An investigation of the anatomy of the stem of the hybrid supports the views arrived at above on purely morphological

grounds. The influence of *P. Millardii* is most marked in the outer regions of the stem, whilst that ×*P. nitens* (or its parents) appears chiefly in the stelar region.

Taking the cortical region first, we note the one circle of cortical lacunae and the strong sub-epidermal sclerenchyma, clearly characters inherited from *P. Millardii*. The more or less complete hypodermal layer of cells noted in some of the specimens must, however, have been derived from ×*P. nitens*. An anatomical character of greater assistance in solving the identity of the second parent, is the absence in the stem of the hybrid of cortical bundles. In *P. gramineus* a ring of strong bundles is always present in the cortical aerenchyma; this in ×*P. nitens* is usually very much reduced, and in many cases is lacking altogether, in spite of Hagström's statement [1] that in ×*P. nitens*, one will always find one or two cortical rings of vascular and bast bundles besides the sub-epidermal strands. Comparing these with the hybrid, it would appear that the evidence based on this character is in favour of ×*P. nitens*.

The stelar characters which provide cogent arguments as to the parentage, are the structure of the endodermis and the number of xylem canals, particularly the median ones. The endodermal cells of *P. gramineus* are strongly laterally compressed and heavily lignified, but the thickening is unilateral, producing the so called U-cells of Hagström. In the cross *P. gramineus* × *P. perfoliatus* (= ×*P. nitens*), although the U-type of cell prevails over the thin walled round cells of the latter species (the O-cells of Hagström), it is often considerably modified, occasionally to such an extent, that it approaches nearer to the O-type. O-cells are again met with in *P. Millardii*, but in this case they are strongly and uniformly lignified. In ×*P. Heslop-Harrisonii* the cells are chiefly as in the latter species, but with a tendency to form U-cells particularly opposite the phloem of the vascular bundles. Whilst this clearly confirms that *P. Millardii* is one of the parents of our hybrid, no such conclusion can be drawn with regard to the identity of the other parent, apart from the fact that it must possess U-cells. If, however, the statement by Hagström can be of any guide that, in a cross involving *P. gramineus*, the U-type of cell most often predominates, then, the very weak development of the U-condition in the hybrid may be regarded as evidence in favour of ×*P. nitens*.

This view that ×*P. nitens* is the other plant involved in the cross is considerably strengthened when the number of xylem canals in the steles of the species concerned is taken into account. The xylem canals take the place of what would normally be the xylem of the vascular bundles, and they afford the surest method of identifying the position and number of the bundles, which are usually arranged in three groups, one median and two lateral. The number and arrangement of the canals in the steles of the possible parents is shown in the following table:—

Species.	No. of median xylem canals.	No. of lateral xylem canals.
P. perfoliatus	2	6
P. gramineus	1	2
×*P. nitens* (*P. gramineus* × *P. perfoliatus*)	1 or 2	2—6
P. Millardii	1	0
×*P. Heslop-Harrisonii*	1 or 2	2

[1] Critical Researches on the Potamogetons, Kungl. Svensk. Vetenskapsakad. Handl., Ny. Foljd, LV, 1916.

Assuming then that *P. Millardii* is one of the parents, and there seems little doubt on the evidence presented that this is the case, the presence of two lateral xylem canals in the hybrid limits the choice of second parent to *P. gramineus* and × *P. nitens*. To decide between them, attention must be directed to the fact that two median xylem canals may be present in the stele of the hybrid, for this means that one of the parents, at least, must possess two median xylem canals. As the stele of *P. Millardii* is characterised by only one median canal, then this condition must be satisfied by either *P. gramineus* or × *P. nitens*. Reference to the above table shows definitely that of the two, *P. nitens* only may possess two canals. Clearly then the evidence is strongly in favour of × *P. nitens*.

From both morphological and anatomical considerations, it therefore appears that × *P. Heslop-Harrisonii* is the result of a cross between *P. Millardii* and × *P. nitens*. This view, of course, raises the question of the fertility of × *P. nitens*, itself a hybrid, but judging from the plethora of forms which this plant is known to display, this would seem to raise no difficulty. In this connection, from our observations in the field, we are of the opinion that × *P. nitens* possesses a higher degree of fertility than is generally thought to be the case.

P. perfoliatus L. Common enough in Lochs Grogary, Scarie and Magarlan; also collected from Loch Skealtar. This last mentioned locality is worthy of special note, as this was the only moorland loch from which this species was obtained on North Uist. All previous Outer Island records, with two exceptions from Barra, were from lochs on the machair.

P. crispus L. Locally common in machair lochs, streamlets, etc.; Loch Sandary, streamlet running from Loch Hosta, ditch, Clachan Sands, and lochans, Baleshare.

P. Friesii Rupr. Found only in Loch Mhor, Baleshare.

P. rutilus Wolfg. The discovery of this interesting and rare pondweed in the Outer Hebrides (V.-C. 110) adds additional British habitats to those already known in the Shetlands. The Hebridean stations for *P. rutilus* are located in Lochs Grogary and Scarie on the machair in North Uist, and in Loch Mhor in the Isle of Baleshare, where the species was detected by Prof. Heslop Harrison and myself.

Our specimens were collected from the abundant floating material which had, in the first place, been broken from the growing plants and then washed to the margins of the loch by the prevailing stormy weather. Amongst this débris many other species of pondweeds were to be found, and, judging by the amount of *P. rutilus* observed, it must grow in some quantity in all these lochs. It is interesting to note in passing that *Naias flexilis* was also present in this tangled mass of vegetation. The occurrence of these two species in the same loch is not without phytogeographical significance, and it seems possible that *P. rutilus* may have to be added to our list of Hebridean glacial survivals. By the kindness of Sir William Wright Smith and Dr. N. Polunin, we have been able to compare our specimens with the plants of *P. rutilus* collected by Druce in the Shetlands in 1920, and with material from Bavaria, and find them identical.

In habit this species resembles that of *P. pusillus* L., the stems in each case being long and unbranched. Our specimens, except those from Loch Scarie, lacked flowers and fruit, but winter buds

had been produced in abundance, and, as pointed out by Hagström, they provide a character which at a glance easily distinguishes *P. rutilus* from all allied species. He describes them in his "Critical Researches" as "stretched," by which is meant, of course, elongated—an apt description—as examples 7 cm. in length were present on our plants. By these buds, *P. rutilus* can easily be distinguished from the stiff-leaved forms of *P. pusillus* L. with which it has been much confused in the past.

Other characters which serve to distinguish it from its near allies are its bright grass green colour, its stiff, narrow, long-pointed, 3-nerved leaves, and its persistent, membranous, light coloured stipules, with sheaths tubular at the base. Further, the midrib of the leaves, when viewed against a bright light, appears to be three veined. Actually only one vein is present, the two apparently lateral ones consisting of strong strands of sclerenchyma. In transverse section, these strands stand out conspicuously on the underside of the midrib, as do two similar strands in the margins of the leaf, and it is to these strands that the leaf owes its characteristic rigidity.

Lastly, a transverse section of the stem is a valuable aid in the identification of *P. rutilus*, for it is very strongly compressed. From other "pusilloid" species with similar stems, it can be readily distinguished by the strongly developed sub-epidermal sclerenchyma.

P. pusillus L. Only recorded from Loch Grogary.

P. Millardii Heslop Harrison (= **P. Berchtoldii** Dandy & Taylor non Fieber). Another of the species found in Loch Grogary but also recorded from Loch Mhor, Baleshare.

P. pectinatus L. Abundant in Lochs Grogary and Scarie, and in Loch Mhor and lochans, Baleshare.

× **P. suecicus** Richter (= **P. pectinatus** × **P. filiformis**). Just as common as the last species in the same lochans, Baleshare. Strangely enough, in spite of the occurrence of this hybrid in these lochans, *P. filiformis* was not recorded from them, nor from any of the lochs examined on North Uist.

AGRICULTURAL COMPLEXITIES.

A background to discussions about the future of Agriculture.

By D. H. DINSDALE, M.A.

An address delivered to the Durham University Philosophical Society, 19th May, 1944.

There has recently been a notable crescendo of interest in the future of agriculture. It is evident in many directions, and at various levels of thought, of knowledge, and of influence. Several reasons might be suggested for this quickening of interest, and perhaps the simple postulate that self-preservation is the first law is as good a starting point as any from which one might explain, at least its genesis.

Just as, at the lowest levels of domestic discord, a well-meaning, if flippant, friend will offer the advice, Feed the brute! so also, at the highest levels of international concord, the signatories of the Atlantic Charter have declared one of their aims to be " a peace in which all men in all lands may live out their lives in freedom from want."

By either formula, the contribution of food to the preservation of peace is fully recognised.

But here, in this country, and for the second time in a generation the threat of starvation by blockade has come dangerously near. We have yet to learn the full magnitude of the efforts by which that threat has been averted. Elsewhere and over half the world, the spectre of famine casts its grisly shadow, which is not likely to be easily or quickly dispelled.

Yet, in contrast to these things, and in very defiance of them, by one of the most remarkable concerted and sustained efforts in all our history, a depressed and, as some would say, an almost decrepit agricultural industry has succeeded, in the short space of four years, and against immense handicaps, in reaching levels of productivity and performance not known since the hey-day of the industry's prosperity in the golden years of the 1860's.

It is fitting, it is just, and it is plain common sense that there should be the liveliest interest in the future of agriculture.

All this, however, is little more than a rhetorical prelude to a subject bristling with complexities and problems of practical moment. It is not my purpose to attempt to resolve all the complexities or offer solutions for all the problems. I should regard it as a very high, but thoroughly misplaced, compliment if I were to be thought capable of doing so. I understand, however, that it is some years since agriculture provided the subject matter for discussion at a general meeting of this Society; the inception last year of a new Agricultural Section has, I believe, prompted the choice of topic on this occasion; and it seemed to me, therefore, that my contribution to the Society's proceedings might appropriately take the form of an attempt to set out some part of the background of facts and tendencies against which current discussions proceed, and upon which, eventually, practical policies must work.

Discussions about the future of agriculture have been going on for a very long time. Even before the impact of war gave them special urgency and an immediate point of focus, there were thousands of people up and down the country — many of them knowing little or nothing about the industry itself — who were seriously concerned about the broad outlines of future policy. Not all of them approached the subject by the same route or with the same objectives.

Land fulfils many purposes in addition to being the prime raw material of farming. In this overcrowded island it is so scarce a commodity in relation to the manifold demands upon it, that there is hardly a phase of national activity which does not have some bearing upon its purely agricultural uses and which therefore impinges in greater or less degree upon the activities and interests of those who follow the plough.

A brief survey of the main lines of approach to the question, what is to be done about farming? would reveal something like this.

First of all there are those who believe that prosperous farming is both desirable for its own sake and necessary to a balanced national life. They view with concern the increasing dilapidation and waste of national assets in the fertility of land and its farming equipment and are anxious to see the end of chronic agricultural depression. Others approaching the matter from the standpoint of national health and dietary standards now wish to see greater production of the vitamin-rich foods such as milk, eggs, fruit and vegetables, and greater certainty that these protective foods will reach those sections of the community who need them most.

A variation of this approach regards the countryside and its people as a reservoir upon which the country must continue to draw to maintain the stamina and vigour of urban populations wearing out under the nervous stress and physical strain of modern city life.

From a different angle, in relation to deep - seated problems of industrial unemployment, the possibilities of land settlement continue to be actively canvassed.

Then again, questions of national defence, and of insurance against the risks of starvation by blockade, have always had their protagonists in the field of agricultural policy.

On a somewhat different plane are those who see in farming a way of life, the rewards to which lie outside the accepted scales of commercial remuneration; which, in its own mysterious ways, has imparted virtue to the English character; and which, on that account, must be preserved.

There are those also who, on grounds compounded of aesthetic taste, sentiment, traditional rights and other imponderable

elements, campaign vigorously to restore and develop the old village crafts and culture; to preserve and extend recreational facilities in, and public rights of access to the countryside.

Others, arguing from the more technical standpoint of industrial efficiency and earning power, would propose the most drastic re-organisation of the industry in terms of land ownership, land management, the size of farm units, mechanization, and the marketing structure.

These widely different schools of thought and aim have a positive bearing on the future of agriculture in the sense that they call for action in the agricultural sphere itself. By contrast there is a by no means insignificant section of opinion which, while not necessarily antagonistic or indifferent towards agriculture, is yet negative in that its supporters would be content to allow the industry to derive what benefit it could from a policy aimed at promoting the prosperity and full activity of the non-agricultural industries and branches of commerce through which the main main streams of purchasing power are distributed.

Lastly at the highest level of international dealings, there are over-riding considerations arising from the simple fact that, in the matter of food production we are not a self-supporting community. In normal times it must be expected that some proportion of our agricultural needs will require to be imported, and, — so close is the integration of processes and enterprises in our farming systems — these imports must influence the form and scale of the home industry, however skilfully their impact upon the market may be masked and cushioned by protective devices of one kind and another.

The national outlook towards agriculture has long been compounded of these diverse approaches and the debate continues. Yet they are approaches only. Even when they have been established in an approved order of priority—approved that is, not only in terms of a Government programme but also in terms of broad acceptance by that public opinion which is the ultimate foundation of policy, it will still be necessary to take decisions on a wide range of intricate questions, practical and technical, concerning the kind and scale of agricultural enterprises to be encouraged; the modifications to be made to the present economic structure and organisation of the industry; and the specific measures by which the agricultural community of land-owners, tenants, and farm workers may be enabled to provide the services to be expected of them.

These are the complexities of policy—to determine first the aims and second, the means by which they may be reached. What of the medium, the industry itself?

In any consideration of the future it is important to realise that the present structure of the agricultural industry, and many of its customs, its contractual and conventional obligations, and methods of working, are the outcome of centuries of continuous growth and adaptation to a changing environment. Agriculture is the main, though not the only, pre-occupation of the rural population, and its institutions, conventions and outlook have their roots and branches deeply woven into the political, economic, social and spiritual fabric of the nation.

This is not to imply that they must be preserved in status quo because they are old and deeply rooted. It is to suggest one reason why present proposals for change raise so many solid and sometimes unexpected difficulties.

Moreover, and particularly since the industrialization and urbanization of the country during the 19th century, the almost complete divorce between town and country has resulted in a surprising and almost distressing degree of mutual ignorance on either side of the agricultural fence about even the simplest features of events and circumstances on the other.

I hope I may be forgiven for any implied suggestion that this ignorance is shared by my present audience,: but I confess that, in selecting the title "Agricultural Complexities," I reflect my own state of mind and knowledge. I hope it will be considered worth while, therefore, if I now attempt a review of some of the basic features of the industry which is the stake in all these discussions.

First, as to its absolute and relative size in terms of persons engaged.

Although in the world as a whole, about four-fifths of the population are engaged in some form of agriculture, the proportion in Great Britain just before the war was probably less than 10 per cent. The precise figure will depend upon definitions of agricultural occupations.

Both the absolute numbers engaged and their ratio to total population have been declining for many years. This follows mathematically from the multiplication and expansion of non-agricultural industries and pursuits. The effect of technical and scientific discoveries in raising the output per unit of labour, have also contributed. In addition there has been a marked trend towards the depopulation of rural areas, to which I shall need to refer later.

The extent to which population growth, the factory age, and urbanization have contributed to the political and economic eclipse of farming may be illustrated by a simple historical comparison.

A hundred years ago Great Britain had a population of 18½ millions, of whom nearly 16 millions were in England and

Wales. London claimed 2 millions and seven other cities of over 100,000 inhabitants accounted for 1½ millions. About three-quarters of the total population lived in the rural areas and in towns of less than 20,000 people. *

In 1937 the total population was 46 millions, of whom nearly three-fifths lived in London and in 36 cities and city groups each with more than 100,000 inhabitants. †

Nevertheless, despite this most intensive industrialization, and urbanization, agriculture, up to the outbreak of war, was still the largest single industry in the country.

Table I. Output and Employment in Certain Major Industries.

1935 United Kingdom	Value of Output	Employees
Agriculture	£260,000,000	776,000
Iron and Steel	278,000,000	533,538
Cotton Spinning	142,880,000	347,944
Shipbuilding	34,765,000	79,478
Motor and Cycle Manufacture	132,108,000	218,665

I shall return to the question of employment and labour migration, and for the moment, I turn to the structural aspect of the industry, i.e., the system of tenure, the number, size, and character of farm units.

The British system of land tenure is, of course, predominantly a tenancy system, in which, broadly speaking, the landlord bears responsibility for maintaining the permanent fabric—the buildings, drains, roads, gates and so on—and the tenant provides the working capital in livestock and implements, the seeds, fertilisers and other requisites, and is responsible for the farming enterprise proper.

Of all aspects of the industry, the tenure system is probably the most controversial and it is much too big a subject for me to discuss in any detail here. At its best, say up to 80 or 100 years ago, it functioned well and great strides were made in farming technique and efficiency. At that time, "those who owned and managed land were among the most active and influential leaders in public affairs, national and local. They not only shared but took a large part in creating the spirit of their times. Men who were primarily landowners, pioneered new methods and new enterprises not only in agriculture. but also in mining, transport and factory industry, and in the large scale planning of towns."* If they had privileges and political power, they also accepted obligations, and in the management of the great landed estates, their influence and guardianship were

* Arthur Bryant, English Saga, p. 1.
† The Home Market (1939 Edn.) p. 41.
* Planning, No. 181, Nov., 1941, p. 1. † *Ibid.*

exercised over considerable areas, and to a communal plan, rather than farm by farm. The basic feudal principle of service to the State in return for the privileges of rank was still recognisable.

With the rise of the new plutocracy in the 19th century the economic and political balance was completely changed, and " the defeats which British landowners afterwards suffered had more far-reaching effects than is commonly realised. Above all they led to the result that land, instead of being linked with some of the most vigorous and dominant elements in the community became the special province of a depressed, almost persecuted group which tended to look to the past rather than to the future."†

Writing in 1941, the anonymous authors of the interesting series of pamphlets published under the title " Planning," from which I have just quoted, made this comment on the present-day situation:—

> "A nation which is more than three-quarters urban and which begins to concern itself over its land must inevitably do so largely from an urban angle, and it is hopeless, even if it were desirable, to attempt to divert the reviving interest in the subject into the old channels appropriate to the period when we were still a country-dwelling people. The traditional and largely rural-minded landed interest with all its satellite groups has already suffered the misfortune of being deposed from its political, economic, and social leadership in the nation and later of being neglected and penalised, but it has now to suffer the further trial of being rediscovered and remoulded to fit the purposes of a people who have travelled a long way from the country and often need reminding of its very existence.
>
> A revival of interest in our land in the nineteen-forties will not therefore mean anything remotely resembling a return to the ideas or patterns of the eighteen-forties even where those ideas and patterns were justified by their results at the time."

As further evidence of the decline in the position of landlords, it may be noted that since the last quarter of the 19th century a series of Agricultural Holdings Acts (1875-1923) have progressively removed restrictions upon tenants in respect of freedom of cropping and have provided for compensation to tenants both for improvements carried out during tenancy and for disturbance, after notice to quit. The general effect of these provisions, in the words of the late Sir Daniel Hall (1941)* has

* " Reconstruction and the Land ", p. 25. † *Ibid.*

been "to extinguish almost completely the landlord's control of the farming of his land . . . . they became a contributory factor in the recent decline of English farming. Tenancy, which makes the owner responsible for the upkeep of the permanent fabric of the farm has many advantages as a system of tenure; indeed, is the best system, provided the owner possesses both the knowledge and the measure of control which enables him to become, in effect, a working partner of the tenant."

Sir Daniel Hall himself reached the conclusion that the solution lies in the direction of State ownership of land and, after outlining his proposals, said:—

> "Just as many farmers will be apprehensive of any change, so also many landowners will be opposed to the policy here outlined, for it seems to mean the destruction of what little is left of their prestige and of their traditional power in the countryside. To many it will represent the breaking of a long record of connection with a particular piece of land which they have come to know farm by farm, indeed field by field. It is no figure of speech to say of such men that they and their forbears have loved the land and served it generation by generation, acknowledging a responsibility both to the land and to the men who lived upon it, guardians of the public affairs of their district. Had all owners of land been of this quality it is unlikely that any question of their disturbance would ever have arisen."

Whatever the reasons, and whether one approaches the matter from the Right, Left or Centre, there can be little question that over a large part of the agricultural field the functions for which landlords are still held responsible are imperfectly discharged and many of the proposals for future reconstruction are concerned with ways and means for restoring the position.

Whether the solution lies in State ownership or alternative forms of corporate ownership, or in providing guarantees for long term stability under which individual enterprise may again be relied upon to provide necessary capital and control of tenants in the interests of good farming, is one of the larger and more critical questions of high policy.

The form which the administrative machinery may take, however, is or should be less important than the spirit, the energy, and the technical ability which are brought to bear upon the functional responsibility for maintaining the land and its equipment and for safeguarding it against shortsighted and self-interested exploitation.

So far as the provision of capital is concerned, it is relevant to point out that the principle of joint stock enterprise on the basis

of limited liability has never been applied on any scale to agriculture. The farmer's credit-worthiness has continued to rest upon his personal resources and his personal reputation for honest dealing.

Here there is a fundamental contrast with developments in industry and commerce which followed the passing of the Companies Act of 1862. * What the ultimate significance of the contrast may be is indicated by the following quotation:—

> †" The consequences of the Companies Act of 1862 were perhaps greater than that of any single measure in English parliamentary history. They completed the divorce between the Christian conscience and the economic practice of every day life. They paganised the commercial community. Henceforward an astute man by adherence to legal rules which had nothing to do with morality could grow immensely rich by virtue of shuffling off his most elementary obligations to his fellows. He could not only grow rich by such means. He could grow immensely powerful."

From the moral point of view agriculture may perhaps be congratulated on having escaped that degradation!

On the other hand, the late Sir Daniel Hall*, in his review of the present state of farming, took this view:— "The credit obtainable by the farming industry is deplorable; it has no access to the great public sources of capital which all other industries have been enjoying in Great Britain."

Also †" . . . . to the great business world of Britain, the bankers, and financiers, company directors, lawyers, merchants and industrialists, agriculture has become a thing of nought except as an expensive hobby to play the old squire."

All authorities agree that agricultural reconstruction will call for large capital investments and it is becoming more widely recognised that, not only in agriculture, but over the whole economic field, the directions in which capital is invested and the purposes to which it is applied must have more regard for the public weal and the true service of mankind.

In the process of re-discovering agriculture we shall find that it comprised in 1938, about 366,000 farm holdings in separate occupation in England and Wales and 74,000 in Scotland. Of those in England and Wales 62 per cent. were of less than 50 acres and only 3 per cent. over 300 acres. Yet more than two

* The Companies Act of 1862 legalised the principle of limited liability in company finance.

† Arthur Bryant, " English Saga ", p. 219.

* " Reconstruction and the Land," p. 88. † *Ibid,* p. 89.

thirds of the agricultural area was in medium or large holdings of 100 acres and upwards. ‡

There is a further material point. Many of the holdings returned in the Agricultural Statistics, especially in the smaller size groups, are not true farming businesses. They consist of gardens, parks, sports grounds, odd fields and paddocks used for various purposes.

On the other hand, many farms proper are worked in combination under a single management. Consequently the number of farmers is considerably less than the number of holdings. The recent Domesday Survey will throw a good deal of new light on this and other aspects of the farming structure. For present purposes, an estimate by the late Sir Daniel Hall may serve — that of 280,000 farmers recorded in the 1931 census, about 120,000 were employers of hired labour, and more than 150,000 were on the smaller holdings depending on family labour.

A further point of interest is that, taking an over-all average of the farmers employing hired workers, the number of such workers per farmer was round about five. These figures confirm that British agriculture is carried on by a large number of relatively small businesses. Important economic consequences follow from this and from the mixed character of British farming to which I now turn.

To-day, for war purposes, there is close control and direction of the individual farmer's cropping and livestock policies. Farm prices are regulated by statutory order. The free play of the market is rigidly clamped down.

Under pre-war conditions, however, every farm occupier was an independent unit, free, within the elastic bonds of tenancy agreements or as owner occupier, to vary the character and scale of his resources, skill and knowledge, his preferences and personal idiosyncracies.*

Moreover, with a few exceptions such as specialized poultry farms or hill sheep farms, Britain is a country of mixed farms in which livestock and cropping enterprises are closely integrated. Just how mixed, a colour impression of the types of Farming Map

‡ It should be noted that acreage is only one measure of the size of a farming unit. It is not always the most suitable. The amount of capital invested and the volume of employment provided are better for some purposes. Thus, at two extremes, a half acre of land equipped for intensive market gardening and glasshouse production will contribute more to food supplies, and be a bigger business unit in terms of turnover and employment than a 3,000 acre hill sheep farm.

* The Potato and Hops Marketing Boards imposed restrictions on the acreage of these crops.

will show.† Not only is the farmer interested in different commodity markets but also in alternative markets for the same commodity. For example, the characteristic farm in the county of Durham will have a milk producing herd as the main enterprise and in addition may sell wheat, oats, potatoes, poultry produce, pigs and, perhaps vegetables grown on the field scale. The milk may be tuberculin tested, accredited, or of ordinary grade. It may be sold by wholesale, by semi-wholesale (schools, etc.) or by retail. The oats may be sold either as grain or through livestock. The pigs may be sold as weaners or fed to pork or to bacon weights. Potatoes may be sold on lifting, or stored against a prospective rise in prices. Over the whole field of production, with every shift in prices, the comparative advantages of one crop against another, one class of livestock against another or one market against another would be re-assessed. Adjustments and adaptations were constantly being made in a continuing process of trial and error.

The mixed character of British farming is also indicated by the number of different breeds and cross-breeds of the various classes of livestock and the many different varieties of particular crops. All these make for variety in the type, quality, and seasonality of the farming output.

The predominance of small businesses in farming has another consequence which deserves notice.* In the engineering or textile industries the proportion of masters to men is perhaps one to a hundred and often more. In farming the ratio is one to five or six. This means that those individuals responsible for the *direction* of farm enterprises — the entrepreneurs — have been subject to less selection than in other branches of production. Consequently the range in individual managerial efficiency is much wider. Moreover, it is only on the relatively few large farms that there is scope for the delegation of responsibilities to intermediaries between master and men or for the employment of subsidiaries like book-keepers, storekeepers, mechanics, and so on.

The resulting wide range of efficiency in management is one explanation why investigations into farming costs — whatever the product investigated — invariably reveal wide variations between farm and farm.

Taking together the large number of farming units, their small average size, their mixed organization, and their wide range

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† Types of Farming Map, England & Wales, Ministry of Agriculture & Fisheries, 1941, which distinguishes 5 pasture types, 6 intermediate types, 6 arable types and 3 various other classes of land.

* "Reconstruction and the Land," p. 72.

in efficiency, it is not difficult to understand why the regulation of farm prices raises such thorny problems or why the industry itself finds difficulty in formulating its own clear-cut policy.

I mention two further considerations —

(i) While the residents of, say, Jesmond, Byker and Rye Hill expect three meals a day for 365 days in the year, nature limits the farm to producing one crop per year, whether of potatoes, wheat, calves, or lambs. Even the most perishable product — milk — is subject to seasonal fluctuations in the volume of production.

(ii) Few farm products leave the farm ready for household consumption. The farmer sells a pig — the housewife wants a pound of back rashers, cut thin and not too lean. The housewife buys bread or flour, not wheat; milk by the pint and not by the churn.

Consequently, while there is a good deal of direct selling from farms by retail, the bulk of farm produce passes through a vast network of wholesale and retail selling agencies and most products require further processing after leaving the farm.

Some idea of the size of the gap which separates primary producers from their final customers may be gathered from these figures. Retail expenditure on food before the war was of the order of £1,500 millions per annum. Of this it has been estimated that about £850 millions was absorbed in transportation, distribution, and processing. Of the balance, approximately £400 millions went to overseas primary producers and £250 millions to home primary producers.

On the face of it there might seem to be ample scope for securing such economies in distributive costs as would enable consumers' prices to be substantially reduced, whilst maintaining or even raising the primary producer's share in those prices.

This is another of the more vexed questions of policy on which a considerable amount of detailed study is still required. The shopping habits of housewives are not matters on which I dare venture to offer much criticism but I presume we are all aware of the great increase in the sale of packet foods, canned goods, pre-cooked foods and the like; and of the extent to which shopping by telephone has, on the one hand, encouraged frequent purchases of small quantities, and on the other, reduced the customer's opportunities for inspection and price comparisons.

The following comments by Sir Daniel Hall on the meat trade may serve to illustrate how the personal idiosyncracies of the final customer are linked up with fundamental questions of agricultural policy.

"Of old the butcher had to be possessed of considerable skill in estimating the value of the stock which he bought on the hoof, either in the auction mart or directly from the farmer; he had to judge weight in many cases, as well as quality and suitability to his market. He had further to provide for the killing, hanging and cutting-up, all operations calling for some technical knowledge. But in the large towns nowadays the butcher receives a daily circular from the wholesalers, which carries a pretty exact guarantee of quantity and quality; from this he can order by telephone what his expected trade for the day will require. It is this shift in the method of trading that of late years has made it so difficult to sell the poorer cuts of English meat; the butcher has no longer the responsibility of getting rid of the whole carcase and limits his trade in English meat to the selected joints; for the cheaper cuts people prefer to turn to chilled or frozen meat. To this alteration in habits, both of the consumers who want to do their ordering by telephone and to confine their cooking to what can be done in the frying-pan, and of the butchers who want to be relieved of responsibility and do a small select trade at a high rate of profit, has been due the blight that has fallen upon the trade in British fat stock."

These references to some of the factors responsible for the high retail cost of food indicate how the fundamental considerations underlying a sound food policy may take us a long way from the farm. But they go much further than the housewife's natural desire for easy housekeeping. They go to the roots of the problem of 'poverty in the midst of plenty' and the policy of creating artificial scarcity to maintain prices. Witness Sir Daniel Hall on this aspect of the matter.

". . . . In matters of food the principle of substitution is most apparent. There may be an apparent superfluity of wheat for the needs of the population, on the basis that one unit of the population will consume about 300 lb. of wheat annually and cannot be made to eat more, but wheat can be transformed by the farmer into pigs or into eggs, a process involving a great reduction in the energy obtainable from the food, i.e., in the amount of basic food capable of sustaining life. In order to make a pound of pork, from five to six times as much wheat will be consumed as would be required to make a pound of bread, so that the superfluity of wheat can be indefinitely reduced if it is converted into the higher forms of animal nutriment such as meat, eggs and milk. That it is not so converted is due to the poverty of the buyers, who in

spite of their preference for bacon and eggs, are forced to buy bread because it is the cheapest of foods. In turn the farmers are forced to produce more wheat because the market for the higher foods has become restricted; the surplus of wheat is a product of scarcity at large. Further, if to help the farmers the price of wheat to the consumer is artificially raised the poverty of the consumer is increased — they are forced to live more upon bread and to cut down upon meat, so that actually more wheat is both consumed and produced in consequence of its higher price, for it still remains the cheapest of all foods upon which to support life. So poverty breeds poverty as the cycle of scarcity progresses."

So far, apart from my earlier references to the system of tenure, I have said little of the main historical trends in the economic experiences which have moulded the present-day outlook of the farming community. These matters are very relevant to the question of future developments.

In the short time at my disposal I can best deal with the events of the past seventy-five years by reference to the general course of farming prices. (See graph). The significance of the broad ups and downs will be the more readily understood if I first explain certain disabilities under which agriculture, by its very nature, is compelled to work, disabilities which make adjustment to rapidly changing conditions much more difficult than in many other industries. The difficulties arise from the long lag in production and the close integration of enterprises in mixed systems of farming. The effect of the lag is that production costs accumulate for long periods before the product is sold. Thus land ploughed last autumn may be sown to mangolds this year for the feeding of ewes or dairy cows next March or April. The dairy cow is normally nearly three years old before she produces milk for sale, and so on. The second factor — the integration of enterprises — means that changes in cropping plans and feeding policies must wait on the seasons, the processes of nature, and the balance of cropping acreages in rotational systems.

The general result is to increase the farmer's difficulties in a period of falling prices by disturbing, to his disadvantage, the normal relation between produce prices and costs and thus diminishing or entirely absorbing his margin of profit.

These consequences are of most importance when prices fall through monetary causes. The effect may be summarised broadly as follows: —

" The farmer lays out his money from the beginning of the season onwards, in such farm requisites as he may require,

seeds, fertilisers, feeding stuffs, labour and machinery, and in the costs of ploughing and sowing, etc. When he comes to sell his produce at the end of the season, he finds that prices all round have fallen, with the consequence that he makes greatly diminished profits, or no profits at all. In the first year of falling prices, the farmer probably accepts these events mainly as the results of a " bad season ", and endeavours to make the best of it. In the following year he probably finds that the prices of such requisites as feeding stuffs, fertilisers, seeds and machinery have fallen, while rent and wages have remained fairly stationary. But the cheaper costs of the former avail him little, if at the end of the second year he is confronted with a further drop in produce prices, Gradually, as the process continues, the cost of production *relative to the price of the produce* increases, until conditions are reached which become intolerable; the farmer must then reduce wages or obtain a reduction of rent or become bankrupt. In a prolonged-period of falling prices the average cost of labour in relation to produce prices has remained relatively high.* It is here, therefore, that the farmer has felt the consequences of falling prices most accutely. When economic pressure of this kind has reduced him to a point of extreme difficulty, he has justly sought a reduction of rent, and in this matter he has been dependent very largely on the goodwill and common sense of the landlord. "*

Here then we have the short range tactics and long range strategy of defensive action by the industry against falling prices. Wages and rents, in this order, have hitherto borne the brunt of pressure. Rent adjustments however, take place slowly, and wages have been statutorily regulated since the last war.

While relief through wages may first be sought by reducing wage *rates*, over longer periods of depression these methods will be inadequate and more radical measures to reduce the demand for labour will be taken. In other words, the arable land, on which a large part of the demand for labour arises, will be laid away to grass and men will be discharged. The grass feeding of cattle and sheep will take the place of corn growing. Gross output on the farms concerned will be reduced, but the prospects of profits will be improved. On farms suitably equipped and located, farmers are likely to turn towards those enterprises providing a quicker return to expenditure, e.g., milk production, poultry and pig production. Where this change takes place the demand for labour is likely to be maintained and even increased.

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* When prices are rising the opposite case is usually found.
Report of the Committee on the Stabilisation of Prices (1925) pp. 11, 12.

England thus becomes more and more the 'green and pleasant land' of poetic fancy—though largely in appearance only.

The greater rigidity of wage rates under statutory regulation and the maintenance of wages at levels higher than they might otherwise be, also prompts the substitution of mechanical for manual labour. A tendency towards greater mechanization of farming processes was already much in evidence before the war. It has been greatly intensified during the war, though less on account of high wages. The compelling forces have been the sheer necessity of greatly enlarged operations and the more pressing alternative calls upon man power. Costs have been less important than results.

That these tendencies have been at work over the past 70 years is clearly shown by the agricultural statistics. (See Graph and Table II).

Table II. England and Wales: Main Cropping and Livestock Changes, 1870-1939.

(000's omitted)

	1870.	1901.	1921.	1931.	1399.
Population	22,090	32,526	37,887	39,988	—
Crops & Grass (excluding Rough Grazings) ...	25,957	27,517	26,144	25,283	24,643
Tillage	11,601	8,786	8,997	6,939	6,862
Temporary Grass ...	3,165	3,263	2,549	2,581	2,072
Arable	14,766	12,049	11,618	9,582	8,935
Permanent Grass ...	11,108	15,399	14,526	15,701	15,709
Wheat	3,375	1,665	1,976	1,197	1,683
Total Cattle	4,362	5,535	5,517	6,065	6,770
Cows and Heifers in calf and in milk ...	—	2,168	2,501	2,791	3,105
Sheep	21,647	18,976	13,382	17,749	17,986
Cattle per C. & G. ...	16.8	20	21	24	27
Sheep per C. & G. ...	83.4	69	53	70	73

There have been two major depressions—1875-1895, 1921-1933.

In both, monetary factors determined the onset and duration of the depression.

In both, the tillage acreage was drastically reduced, the permanent grass acreage was enlarged, and the cattle population increased, especially of dairy stock.

The growing of fodder crops declined substantially and there was an increasing reliance upon milling offals, oil cakes, and other animal feeding stuffs. Relevant statistics are given in Table II above.

In both periods, imports of food have been an important contributory factor. In the earlier period, the effects of the development of rail and steamship transport in connecting the virgin soils of the New World with the markets of Europe were more obvious to contemporary observers than the underlying effects of currency appreciation through a world shortage of gold.

In the second, the world wide adoption of policies of economic nationalism by which nations sought to escape from the choking bonds of reparations and war debts, gave the British market the unenviable distinction of being the only free market for export surpluses. In the field of international barter, the home agricultural industry was largely discounted.

Thus in 1930,‡ this country, with less than 3 per cent. of the world's population, took in of the world's exports of —

Bacon and Ham...	99%
Mutton and Lamb	96%
Butter	63%
Eggs	62%
Beef	59%
Cheese	46%
Wool	32%
Wheat and Wheat Flour	28%

Between 1925 when the Gold Standard was resumed and 1931 when it was again suspended, the total volume of food imports into the United Kingdom increased by 23 per cent.

The way in which the persistent downward movements in prices have exerted their pressure upon the individual farmer may also be illustrated thus: In order to meet an annual charge of £300, for rent, wages bill, etc., a farmer needed to sell

in 1920, 290 cwts. of wheat, or 6 Fat Bullocks, or 2,720 galls. of milk,

in 1925, 490 cwts. of wheat, or 10 Fat Bullocks, or 4,840 galls. of milk,

in 1930, 750 cwts. of wheat, or 12 Fat Bullocks, or 5,085 galls. of milk,

Nevertheless the broad changes in the character of the agricultural output, brought about by pressure of economic circumstances, were closely in line with the developments now asked for by those who approach agricultural policy from the nutritional standpoint. (See Table III).

† "The Planning of Britain's Food Imports." Murray & Cohen (1934).

Table III. Changes in the Proportionate Composition of the Agricultural Output between 1908 and 1938-39.

	Per Cent. of Total Value. 1908.	1938-39.
Poultry and Eggs	3.2	10
Potatoes	4.9	5
Fruit and Vegetables	6.5	15
Other Crops	10.6	5.5
Sheep	10.6	7
Pigs	10.6	11
Cereals	13.0	4.5
Cattle	20.3	12
Milk (including Butter and Cheese) ...	20.3	30
	100	100

These, then, are some of the events which lie behind the reiterated demands of the farming industry for stability of prices and security guarantees. The tradition of depression whose foundations were laid in the 70's has passed into the third generation, and, as the following quotation indicates, some of the worst consequences of depression are not susceptible to to statistical measurement.

Sir William Ashley, in a memorandum submitted to the Agricultural Tribunal of Investigation (1924) said:*

> "It is realised that the industrial wastage, the deterioration of human character, which is likely to accompany any period of extreme depression, is not repaired by subsequent periods of prosperity: that depression, in fact, is never completely recovered from, but always leaves behind it a long trail of social and economic evil. That being so, stability on a satisfactory level is rightly becoming part of the social ideal towards which the public will and conscience are moving."

Perhaps the outstanding contrast between the two major depressions to which I have drawn attention lies in the attitude of the State. In the earlier period the national belief in the value of unrestricted free Trade was hardly shaken and agriculture was left to work out its own salvation. Older members of the audience will perhaps remember the vigorous but, on the whole, unsuccessful campaign for Tariff Reform in the early years of the present century.

* Cmd. 2145, p. 238.

In the second period a general protective policy was adopted. It would take too long to trace the various steps by which the policy was brought into operation but the general economic situation between the two wars is of sufficiently recent memory to most of us. It is worth while noting, however, that a good deal of the protection given to agriculture was less a primary aim of policy than a necessary consequence of attempts to safeguard the exchange value of sterling in the interests of export trade—a sobering reflection in the light of present-day discussions, which follow much the same pattern. However, by 1931 the state of agriculture had become a major issue of national policy and the first Agricultural Marketing Act, passed in that year, marked the first step in a positive policy of agricultural re-organisation on a long-term basis. The method may seem curious, in that it took the form of encouraging the formation of National or Regional producer-controlled Marketing Boards with wide monopolistic powers. Their field of operations, the home market, was safeguarded by a wide range of import duties, trade agreements, quota regulations and internal subsidies.

Under this Act and the second Agricultural Marketing Act of 1933, several Marketing Boards were brought into being, the more important being those dealing with milk, potatoes, pigs and bacon, and hops. It is interesting to note, in view of the prominence given to large-scale marketing organisations in current proposals for agricultural reconstruction, that these first experiments during the few years up to the outbreak of war, when many of their functions were taken over by the Ministry of Food, had been directed mainly to securing increases in producer's prices and the stabilisation of markets, but they had made little impression on the fundamental problem of reducing prices to the consumer. It would not be appropriate, however, to condemn the Marketing Board type of machinery on the basis of this short period of experience. For this country it was largely an unexplored and untried field and agriculture's over-riding need for stability of prices over long periods is not likely to be met without machinery of this kind.

The outward and visible signs of depression and of changes in the economic and social outlook of the countryside as they affect the rural worker remain to be discussed.

In crude figures the numbers of male workers of 10 years and upwards, employed in agriculture in Great Britain declined between 1871 and 1901, from 1,543,900 to 1,351,700, a fall of nearly 12½% and between 1927 and 1939, as follows:—

Great Britain:			Decrease
Regular Workers—	1927.	1939.	per cent.
Males, 21 years and over	512,661	431,978	15.7
Males, under 21 years ...	156,511	114,120	27.1
Women and Girls ...	82,115	54,703	33.4
Total Regular Workers	751,287	600,801	20.0
Casual Workers—			
Males, 21 years and over	72,937	64,094	12.1
Males, under 21 years ...	21,413	7,834	63.4
Women and Girls ...	48,087	38,533	19.8
Total Casual Workers ...	142,437	110,461	22.4

It is easy enough to establish the fact of declining numbers, and especially of younger workers and female workers. It is less easy to assess the causes. Migration from the land has always been a feature of British social life.† Expanding industries and commerce; the call of the sea; overseas colonisation; and the wider opportunities of urban life have all played some part. Economic depression and declining arable farming have already been mentioned.

During more recent years, in which the movement of labour out of farming has been intensified, disparities between urban and rural wage standards have often been quoted as the main responsible factor. Current demands for parity between industrial and agricultural wages suggest that there are still people who view the matter largely as a question of wage rates. There is increasing recognition, however, that the matter goes much deeper and that it involves the whole conception of rural life, its working conditions and social environment. Rural housing standards, educational opportunities, recreational facilities, and a psychological revolt against traditional conceptions of the countryman as a clodhopper or a village boor, are all elements in the situation.

Broadcasting, the cinema, and the invasion of the countryside made possible by the popular motor car and the char-a-banc have invited and stimulated comparisons and opened up vistas which the livelier and more adventurous have not been slow to follow.

On the other hand, farming itself has changed and now requires a more highly trained and more adaptable class of worker. While most of the younger men to-day show great keenness to

* Report of Committee on Stabilisation of Prices, 1925, p. 15.
† Sir Daniel Hall. " Reconstruction and the Land ", p. 81.

operate tractors, there is less enthusiasm for the stockman's tasks, which now call for appreciation of the principles of rationed feeding, hygienic precautions in the handling of milk, and other technical matters in which considerable advances have been made.

In addition, therefore, to sociological remedies for rural migration, more positive training of the agricultural recruit in the craftsmanship of his job may be expected to take a large part in future policy.

And now, in concluding what I myself can only describe as a discursive, superficial, amorphous and unbalanced attempt to outline some of the complexities which lie behind discussions about the future of British Agriculture, may I refer to a comment which Lord Cranbourne is reported to have made in the House of Lords last Wednesday—that so far the only body which has not produced proposals for the future of agriculture, is the Ministry of Agriculture itself!

The Ministry of Agriculture, of course, are much more fully informed about these matters than I am, and nothing that I have said will be either new to them or likely to assist them in their responsible task.

I would hope, however, I have said enough to make it clearer that the task itself extends far beyond the responsibilities of Ministers. It is one to which all sections of the body politic have at some time or other contributed their quota of confusion, and may now, if they will, contribute their share of constructive thought, of positive action, and of wide tolerance.

May, 1944.

THE FALL OF RAIN

By E. G. RICHARDSON, B.A., Ph.D., D.Sc.

Condensation of water vapour in the atmosphere to form clouds appears to occur when a condition of saturation of water vapour and the existence of hygroscopic nuclei are established in upward convection currents. The force of gravity causes the (water or ice) droplets so produced to travel upwards less slowly than the air current as they grow until eventually they are moving downwards out of the original cloud as rain (or snow) and fall to earth unless they evaporate completely en route.

It is with the latter process that this Note is concerned. We shall assume that, clear of the original cloud, we are dealing with single drops, i.e., that there are no collisions with other drops or with " smuts " floating in the air.

Free Fall and Resistance

Suppose a drop of radius r, surface s ($=4\pi r^2$) to be released at a height h when stationary relative to the air. It commences to fall under the gravitational acceleration but is at once checked by the resistance of the air and eventually reaches a terminal (steady) velocity c, which is a function of Reynolds Number, Re. Stokes' law says that $c=ks$ where k is a constant for given densities of liquid and air, and for rigid spheres, but for those sizes for which the speed attained involves $Re > 1{,}000$, the terminal velocities fall away from this partly because the motion is no longer streamline and partly because the liquid inside the drop begins to rotate.

The Table gives times t_1 to reach 95% of c, starting from rest, and times t_2 to fall 100 metres at this velocity. The terminal velocity of drops—$c.obs.$—are from data of Lenard[1], Liebster[2] and Lunnon[3].

Table 1

2r (mm.)	·10	.15	.20	.25	.30	.35	.40
s (cm$^2\times 10^{-4}$) ...	3.14	7.2	12.5	19.5	28	38	50
c=ks (m/sec.) ...	.33	.75	1.32	2.10	2.95	4.0	5.3
c.obs. (m/sec.) ...	.33	.65	1.15	1.40	1.75	2.0	2.2
t_1 (sec.)	.10	.20	.35	.43	.53	.61	.67
t_2 (sec.)	300	100	87	71	57	50	45

2r (mm.)	.50	.60	.70	.80	.90	1.00	
s (cm$^2\times 10^{-4}$) ...	79	112	152	200	252	312	
c=ks (m/sec.) ...	8.2	11.8	16.0	21.2	26.5	33.6	
c.obs. (m/sec.) ...	2.8	3.4	4.0	4.6	5.[illegible]	5.4	
t_1 (sec.)	.86	1·0	1.2	1.4	1.5	1.6	
t_2 (sec.)	36	30	25	22	20	19	

1 Lenard, Met. Zeits., 39, 249, 1904.
2 Liebster, Ann. d. Physik, 82, 541, 1927.
3 Lunnon, Proc. Roy. Soc. 118A, 680, 1928.

Evaporation

At the same time that it is falling the drop loses mass by evaporation. Actually it is a balance between the diffusion of molecules from the drop into the vapour surrounding it and those which condense into the drop. If the boundary layer of molecules is not swept away by convection this is purely a problem in diffusion for which Langmuir[4] has derived the formula:—

$$-\frac{ds}{dt}=\frac{4\pi MDp}{\rho RT}=k'\frac{p}{T}$$

where M = molecular weight, R = gas constant, D = diffusion coefficient, T = absolute temperature, ρ = density of liquid and p = its saturation vapour pressure. Inserting the appropriate values for water we find the following values for the rate of evaporation, ds/dt.

Table 2

Temperature.	p/T.	ds/dt.
0°C	27.5	1.4×10^{-5} cm.^{2}/sec.
10°C	35	2.5 ,, ,,
20°C	41	4.5 ,, ,,

An experimental value obtained by Whitaker for water at 15°C. is 3×10^{-5} cm.^{2}/sec.

It is evident that over the range of terminal velocity for which Stokes' Law holds, every drop suffers a constant deceleration (due to evaporation) whatever its size, while the temperature is constant, of

$$\frac{d^2h}{dt^2} = -k\frac{ds}{dt} = kk'\frac{p}{T}$$

Thus for small raindrops at 10°C. this deceleration is 3 cm^2/sec.

Langmuir's equation does not contain any term covering convective evaporation, i.e., no term involving the speed of the drop through the atmosphere into which it is evaporating. The rate of evaporation is in fact a function of Reynolds Number (Re). This has been proved experimentally by Frössling[5] who held water drops on glass threads in a small wind tunnel and measured the rate of decrease of mass at various wind speeds. He found that the right-hand side of Langmuir's equation must be multiplied by $\left(1+\frac{.276\sqrt{Re}}{\sqrt[8]{D/\nu}}\right)(1+0.1\sqrt{Re})$, for water at 20°C. ($\nu$ = Kinematic viscesity.)

[4] Langmuir, Phys. Rev., 12, 368, 1918.
[5] Frössling, Beit. z. Geophysik, 52, 170, 1938.

Height: Surface Curves for Drops

Armed with these data we can trace the change in size and speed of a drop as it falls at any constant temperature. The dotted curves on Fig. 1 show the relationship between terminal velocity and surface (or r^2) for a given rate of evaporation (ds/dt) by reversing its path and assuming it starts from nothing at ground level and has its surface increased with height by a constant amount for every 10 secs. of its life (cf. time scales at top of figure). This gives us the right-hand dotted curve, but owing to convectional evaporation the life-time of a droplet is reduced, in other words, we must correct this curve by calculating values of Reynolds number at various epochs—these are shown alongside the curve—and moving each 10 sec. point to the left so that, for instance, an increment of surface 2×10^{-4}cm.^{2} takes place in $10(1+0.1\sqrt{Re})$ secs. instead of 10 secs. The corrected velocity: surface curve is the left-hand dotted one.

Starting from ground level it is then possible to calculate by steps the height at which a drop will have a given surface (or size) if its life history is reversed. These heights are marked (in metres) for 10 sec. steps alongside the corrected curve. Height: surface curves can then be plotted. Several of these are shown on the figure (as full lines) for three values of ds/dt. If a drop posseses a definite size on hitting the ground instead of being evanescent as we have assumed, it is only necessary, in order to apply the graphs, to assume the ground to be raised to meet it by the corresponding amount. Thus, if $ds/dt = 3 \times 10^{-5}$cm.^{2}/sec. and the drop is $\frac{1}{4}$ mm. diameter on hitting the ground (i.e., remnant surface 20×10^{-4} sq. cm.), " ground level " must be pushed up 50m., or 50m. subtracted from all heights on the scale to the right of the figure.

Experimental Work

Recently the writer had the opportunity of making some measurements on the fall of water drops in an enclosed tower nearly 40 metres high. Drops were allowed to fall from a fine burette and their " initial size " measured by photography 10cm below the mouth of the burette. Their time of fall to the bottom of the tower, where they were caught on blotting paper, was measured by chronometer. The water was dyed so that from the size of the stain—after a preliminary calibration—the " final size " of the drop could be deduced. Drops of a saturated solution of zinc chloride were also used.

Fig. 1 shows, as would be expected, that small drops suffer the greatest loss of mass. At ds/dt equal to 3×10^{-5} cm.^{2}/sec. a drop initially 0.25 mm. in diameter at the top of the tower

will just disappear before hitting the mat. On Fig. 2 the lines represent the theoretical relationship between the time to fall this height and the diameter, while the circles and crosses represent the actual values for water and the solution respectively, at 15°C. Although, in principle, it should be possible to deduce the rate of evaporation appropriate to a given temperature from the observed times of fall, in the light of the theory given here, it is doubtful whether the accuracy of the present measurement of times warrants this. On the whole, the water experiments indicate rather higher values of the rate of evaporation than those derived from the Langmuir-Frössling formula.

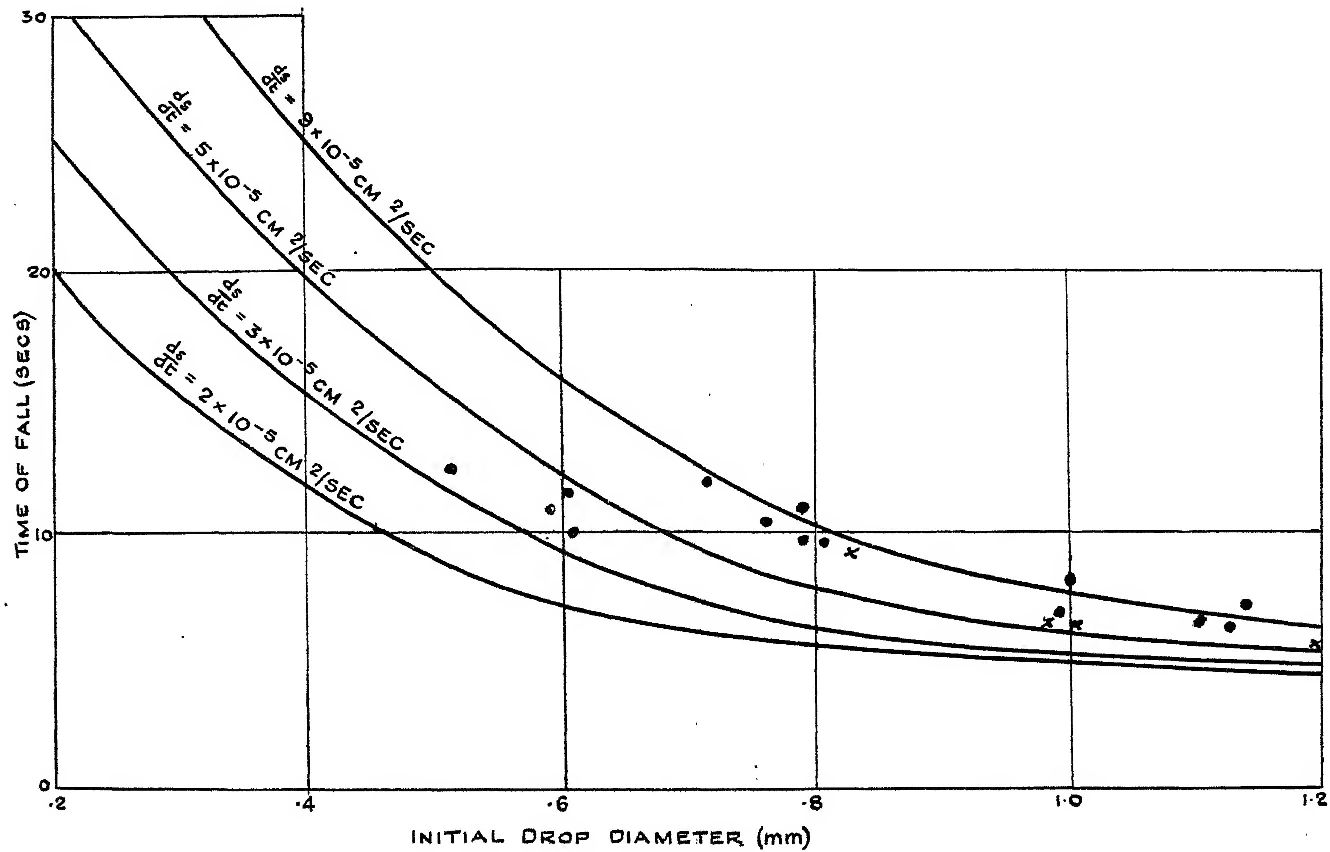
One peculiarity in the experiments deserves mention. No drops reached the mat having a smaller initial size than 0.4 mm. Some of these would go astray in light draughts in the tower, but some were observed actually petering out as they passed higher observation points on the spiral staircase which runs up the tower. This might be taken to indicate an abnormal ds/dt for little drops but it is more likely that the small inertia of the fine drops enables them to pursue a sinuous path under the action of the trail of vortices in their wake. The resulting " falling leaf " path of the fine drops was in fact observed towards the end of their lives, indicating, of course, a longer path through the air than the vertical one assumed in calculating results. The same thing might occur in natural rain to larger drops when passing through a stratum of turbulent air.

The results may, one feels, be effected by the cooling of the drops by their latent heat of evaporation. Topley and Whytlaw-Gray[6] have calculated this effect for iodine, of which the latent heat of sublimation is 15,000 cals./gm.; the cooling of 1 mm. drops of iodine from this cause was about $\frac{1}{4}$°C. per sec. Water has a latent heat of 530 cals./gm. so that the cooling in this case, being proportionately smaller, can be neglected as a contributory factor.

Summary

The theory of the fall of single raindrops under the combined effects of gravity and evaporation is discussed and relationships between size of drop and height above ground level derived. Experiments on the free falling of drops and their loss of mass en route are described and the results examined in the light of the theory. The possibility of using such measurements to deduce rates of evaporation is also considered.

[6] Topley and Whytlaw-Gray, Phil. Mag., 4, 873, 1927.



30
20
10
0
TIME OF FALL (SECS)
$\frac{ds}{dt}$ = 9×10⁻⁵ CM 2/SEC
$\frac{ds}{dt}$ = 5×10⁻⁵ CM 2/SEC
$\frac{ds}{dt}$ = 3×10⁻⁵ CM 2/SEC
$\frac{ds}{dt}$ = 2×10⁻⁵ CM 2/SEC
·2
·4
·6
·8
1·0
1·2
INITIAL DROP DIAMETER (mm)

FIG 2.

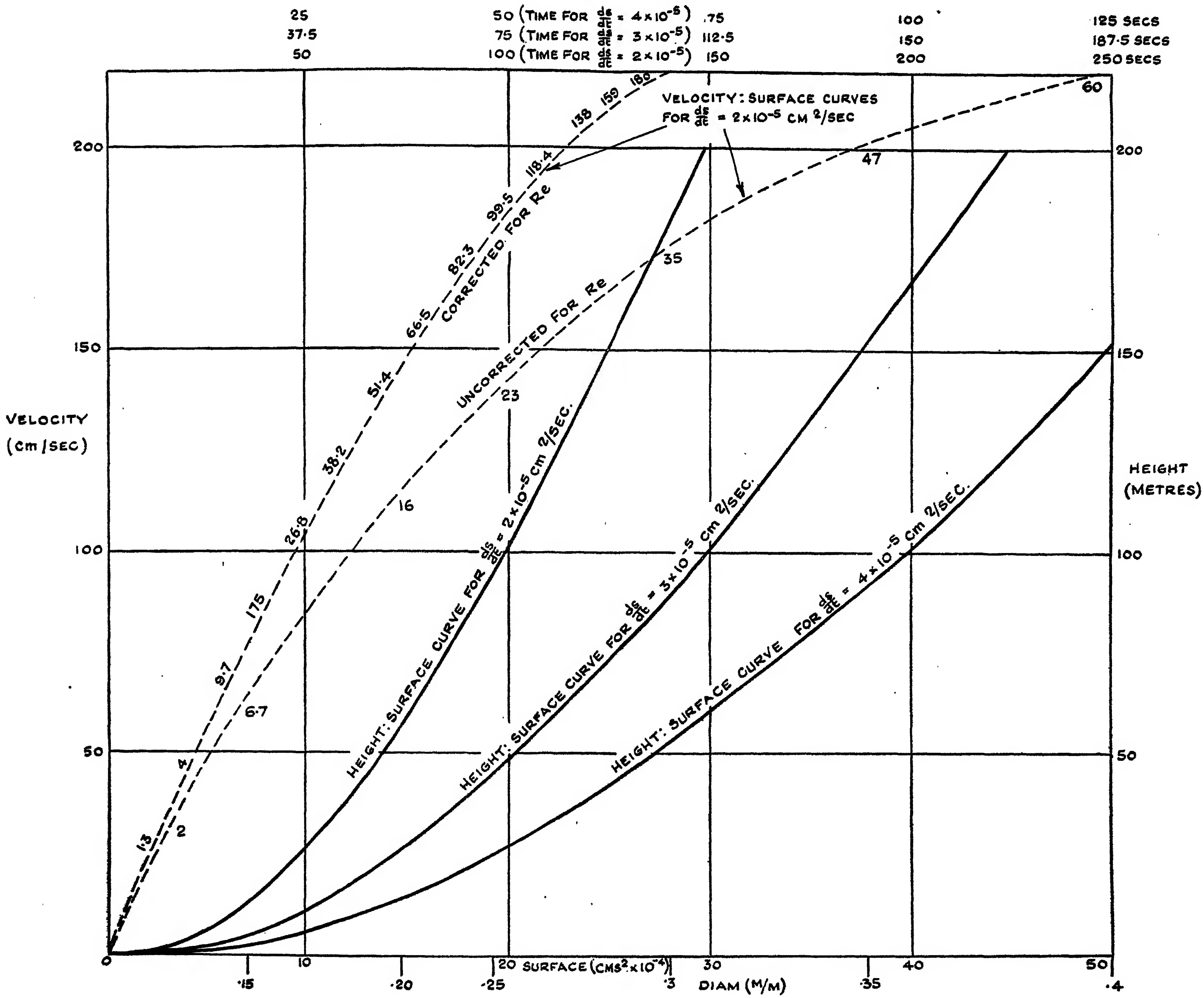

VELOCITY (cm/SEC)
HEIGHT (METRES)
SURFACE (CMS^2 x 10^{-4})
DIAM (M/M)
50 (TIME FOR $\frac{ds}{dt}$ = 4 x 10^{-5})
75 (TIME FOR $\frac{ds}{dt}$ = 3 x 10^{-5})
100 (TIME FOR $\frac{ds}{dt}$ = 2 x 10^{-5})
125 SECS
187.5 SECS
250 SECS
VELOCITY: SURFACE CURVES FOR $\frac{ds}{dt}$ = 2 x 10^{-5} CM ^{2}/SEC
CORRECTED FOR Re
UNCORRECTED FOR Re
HEIGHT: SURFACE CURVE FOR $\frac{ds}{dt}$ = 2 x 10^{-5} cm ^{2}/SEC.
HEIGHT: SURFACE CURVE FOR $\frac{ds}{dt}$ = 3 x 10^{-5} cm ^{2}/SEC.
HEIGHT: SURFACE CURVE FOR $\frac{ds}{dt}$ = 4 x 10^{-5} cm ^{2}/SEC.

FIG 1.

A NEW TYPE OF ELECTRICAL RESONANCE

By ERICH E. SCHNEIDER, Dr.Phil.Nat., A.Inst.P.

(Read February 18th, 1943.)

ABSTRACT.

Utilization of the phase inversion of the thermionic valve leads to a method of obtaining resonance with circuits containing only resistance and capacitance or only resistance and inductance. The distinctive features of these stable "valve resonant circuits" against known RC oscillating circuits and reactance valve networks are discussed and their resonance and impedance properties analyzed in detail. The usefulness of the capacitive form as selective filter and amplifier for very low frequencies is demonstrated. Coupling effects and applications of coupled valve resonant circuits are dealt with. Some oscillators derived from the original circuit are described and their possibilities for a method of frequency modulation considered.

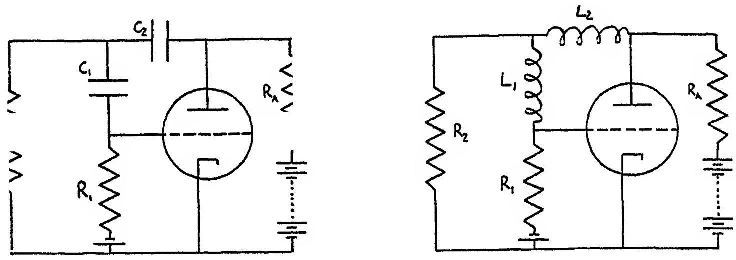
§1 INTRODUCTION

The effect of electrical resonance is usually associated with circuits built up of inductance and capacitance. The essential cause for the resonant action of such "LC" circuits lies in the phase opposition of the two reactance types. Resonance occurs at the frequency at which inductive and capacitive reactance are equal in magnitude, and since they are opposite in sign, the LC combination has zero phase angle at resonance, i.e., acts as a pure resistance. This resistance at resonance represents in a "parallel LC" circuit a maximum and in a "series LC" circuit a minimum of the magnitude of the impedance of the combination. The isolated or "free" LC circuit acts as oscillatory circuit, i.e., an initial disturbance gives rise to exponentially damped oscillations.

The object of this paper is to show a way of producing resonance with reactance of only one type. This is possible through the inherent phase inversion of a thermionic valve, viz., the 180° phase shift between input- (grid-cathode) and output- (anode-cathode) voltage. The valve converts a reactance into one of the complementary type and this converted reactance is combined with another of the original type. Expressed in an over-simplified way this would mean the $(+90^\circ)$ versus (-90°) correspondence of the LC circuits is replaced by a relation $(\underset{(+)}{-}\,90^\circ + 180^\circ)$ versus $(\underset{(+)}{-}\,90^\circ)$. Actually two resistances have to be introduced which are essential and make the phase-shifts different from 90°.

Fig. 1 shows the circuits exhibiting the resonance phenomena, the "capacitive valve resonant circuit" Fig. 1a, and the "inductive valve resonant circuit" Fig. 1b. The capacitive circuit is of greater interest since it allows one to extend resonance effects to frequencies of a few cycles per sec. or lower, a range not accessible to LC resonance.

The general analysis of both circuits and discussion of their resonant properties (§3) will be preceded by a consideration of related work elsewhere (§2). In §4 experimental work verifying the theory is described. §5 deals with coupling effects and in §6



a. FIG. 1. *b.*

some oscillator circuits derived from the simple circuits are desribed and their properties discussed particularly in the light of a possible application to frequency modulation.

§2 RELATED WORK

2.1 Undamped RC and RL Networks.

If the valve is removed from the circuits Fig. 1, they become simple two-mesh resistance reactance networks. Networks of this kind, containing reactance of one type only, were discussed in a general way by TANK and GRAF[1] in 1928. They showed that such networks form always an aperiodically damped system whatever the special arrangement of the resistance and reactance elements in the loops and the linking between the loops. That means in the differential equation for the mesh circulating currents:

$$(A\mathbf{D}^2+B\mathbf{D}+C)i=0 \tag{1a}$$

$$A \text{ and } C>0\,;\ \mathbf{D}\equiv\frac{d}{dt}$$

the damping term ("$\mathbf{D}$-term") is always related to the two other terms ("$\mathbf{D}^2$-term" and "$\mathbf{D}^0$ term") by

$$B^2>4AC \tag{1b}$$

so that the solution is aperiodic ($i=k_1e^{-\lambda_1 t}+k_2e^{-\lambda_2 t}; \lambda_1, \lambda_2$ positive)*

* These results can be extended to a n-mesh resistance-reactance network: The co-efficients of the n-th order equation corresponding to (1)

$$\sum_0^n A_l\,\mathbf{D}^l\,(i) = 0 \text{ are such that}$$

in the general solution:

$$\sum_1^n k_l\, e^{-\lambda_l t}$$

all λ_l are real and positive, i.e., no oscillatory current can occur in any mesh.

The system can only become oscillating or periodically damped if the inherent " overcritical " damping is balanced by a negative resistance, i.e., if through valves or other apparatus external energy is supplied to the system continuously and in the correct phase. Then we get, similarly to the exchange between electric energy of the condenser and magnetic energy of the inductance, an energy exchange between two condensers (or two groups of condensers) in the network, the energy loss in the resistances being made up by the energy supplied from the valves.

The valves make the system less than critically damped. Or expressed in terms of the above differential equation: The valve circuit or other negative resistance introduces a negative part into the **D**-term, the system becomes either self-oscillatory (resulting $B=O$) or periodically damped $i=ke^{-\lambda t}\cos(\omega t+\phi)$. In this latter state it acts similarly to a resonant circuit.

Tank and Graf applied this result to the study of the multivibrator which gives under certain conditions sinusoidal oscillations. The same principle is inherent in all " RC-Oscillators " described in the literature[2-13]. As an illustration one simple form of RC oscillator, the no phase oscillator first described by YATES FISH[4] (the basis of the commercial " Muirhead Decade Oscillator "[13]) is shown in Fig. 2. The " no-phase shift " amplifier N.P.A. can

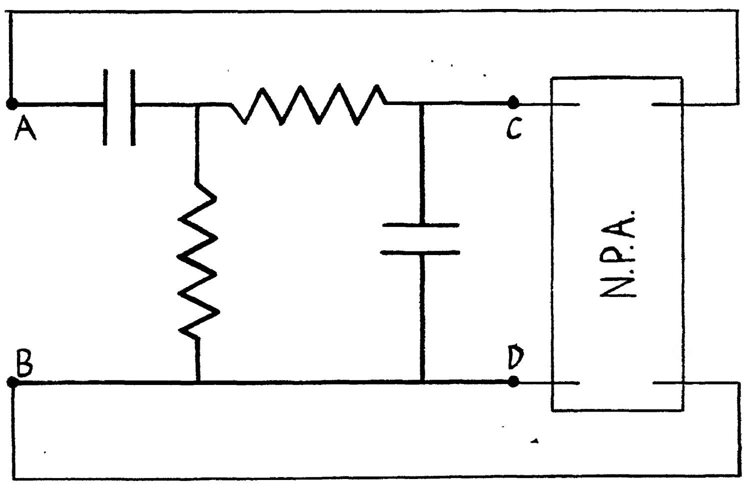


FIG 2.

either consist of two valves in cascade or one valve with cathode or suppressor grid imput[9]. It acts as negative resistance which makes the aperiodically damped resistance capacity network ABCD oscillatory. A non oscillating filter circuit is obtained (similar to

other selective circuits referred to in the literature [13-14]) if the amplification is so adjusted that the negative resistance is just smaller than required for self oscillation but great enough to reduce the damping below the critical value. It is obvious, however, that this adjustment is rather critical, the circuit remains capable of oscillations and is unstable. It is not a proper resonant circuit corresponding to the LC circuit which is stable under all circumstances.

In the circuits described here the situation is quite different. Here the phase inversion by the valve is the essential point and accordingly the circuit is not capable of self-oscillation and is stable under all conditions. As will be seen below, the effect of the valve shows itself not by a negative contribution to the damping term of the differential equation (1) but by a large positive addition to the $\mathbf{D}^2$ or $\mathbf{D}^0$ term, making in this way $4AC > B^2$, the system becomes periodic with a resonant frequency depending on the valve amplification (a useful property, particularly at low frequencies). The damping term is not affected by the valve so that the circuit is stable whatever the valve amplification.

A detailed study of the energy situation in LC Circuits, undamped RC and RL circuits, valve resonant circuits and in resonant systems in general, including mechanical resonance will be published elsewhere.

2.2. Reactance Valves.

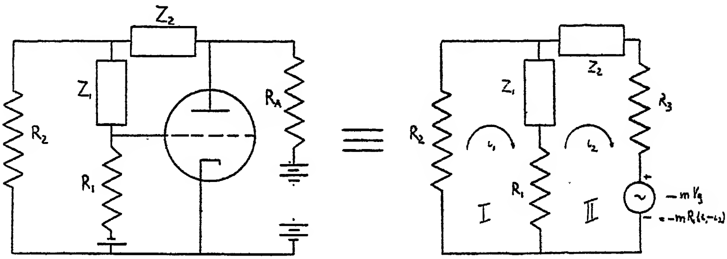
There is a certain resemblance between the circuits of Fig. 1 and reactance valve circuits used for frequency modulation. (See recent surveys by REICH[15] and HUND[16], and a general analysis by E. WILLIAMS[17].) In some of these circuits there is also a conversion of the type of reactance through the valve circuit. But it seems that there the phase inversion is not absolutely essential. Replacement of the valve by a no-phase-shift valve or valve combination would change the reactance type produced but would hardly affect their use in frequency modulators. All the same it would be possible to develop the circuits described here, and another kind to be described elsewhere where resistance and reactance are interchanged, starting from reactance valve circuits, and preferably using Williams' method of analysis[17]. The reason why this resonant aspect has so far not been followed up is probably that the emphasis in reactance valve development lies on their combination with LC circuits and their application to very high frequencies.

§3 GENERAL ANALYSIS

3.1 Fundamental and Equivalent Circuit.

The general scheme of the circuits is given in Fig. 3a, where the Z's represent mainly reactive impedances consisting of pure reactance **H** (capacitive for circuit Fig. 1a, inductive for circuit

Fig. 1b) and equivalent series loss resistance r. The actual analysis is carried out with the equivalent circuit Fig. 3b. Here the action of the valve is represented by a generator of emf $-m.V_g$, and internal resistance R_3 where R_3 is the parallel combination of the valve impedance ϱ and the load resistance R_A ($R_3 = R_A\varrho/R_A+\varrho$) and m the voltage amplification ratio of the valve, given in terms of the mutual conductance g_m by $m=g_m R_3$.* For a pentode valve $\varrho \gg R_A$, $R_3 \approx R_A$, $m \approx g_m R_A$)



a. FIG. 3. *b.*

3.2 Oscillatory Discharge.

For the " free " circuit, i.e., without external voltage we obtain from Fig. 3b applying Kirchhoff's laws to the loops I and I+II:

$$\begin{array}{lll} \text{I} & (R_2+R_1+Z_1).i_1 & -(R_1+Z_1)\,i_2=0 \\ \text{I+II} & (R_2-mR_1)\,.\,i_1 & (R_3+Z_2+mR_1)\,i_2=0 \end{array} \qquad (2a)$$

In matrix notation † (to be used throughout this paper) (2a) can be written

$$\phi \cdot \mathbf{I}_{12} = \mathbf{0} \qquad (2b)$$

where ϕ is the matrix of the coefficients of i_1 and i_2 in (2a) operating on the one-column matrix (or " vector " $\mathbf{I}_{12} \equiv \begin{pmatrix} i_1 \\ i_2 \end{pmatrix}$)

For i_1 and i_2 to be different from zero the determinant of ϕ must vanish

$$|\,\phi\,| \equiv mR_1R_2+R_1R_2+R_1R_3+R_2R_3 + Z_1(R_2+R_3)+Z_2(R_1+R_2)+Z_1Z_2=0 \qquad (3)$$

Substituting for Z the reactance operators **H** and loss resistances r,

---

* All circuits are shown here with a single valve. A combination of valves can be used instead if the phase-shift between input and output is 180° and the over-all gain is constant in the frequency range in question. Then the above analysis is strictly applicable taking for m the overall gain and for R_3 the equivalent output resistance of the valve combination.

† cf. a paper by J. F. Wood in this journal, **9**, 217, 1936, where the application of matrices to physical problems is illustrated.

and putting

$$m' = m + 1 + \frac{R_3}{R_1} + \frac{R_3}{R_2} + \frac{r_1}{R_1} + \frac{r_1 R_3}{R_1 R_2} + \frac{r_2}{R_2} + \frac{r_2}{R_1} + \frac{r_1 r_2}{R_1 R_2} \tag{4}$$

$$(\approx m \text{ if } m \gg 1 \text{ and } R_1, R_2 \gg r_1, r_2, R_3)$$

$$g = 1 + \frac{R_2}{R_1} + \frac{r_1}{R_1} + \frac{H_1}{H_2}\left(\frac{R_2}{R_1} + \frac{R_3}{R_1} + \frac{r_2}{R_1}\right) \tag{5}$$

a dimensionless constant (in practice between 1 and 5), to be called " damping factor," (3) simplifies to

$$| \phi | \equiv m' R_1 R_2 + g R_1 \mathbf{H}_2 + \mathbf{H}_1 \mathbf{H}_2 \tag{6}$$

We have now to distinguish the two types of circuits: For the **Capacitive** circuit the reactance operators are given by $\mathbf{H} = C^{-1}\mathbf{D}^{-1}$ and we obtain from (6)

$$| \phi | \equiv m' R_1 R_2 + g R_1 C_2^{-1} \mathbf{D}^{-1} + C_1^{-1} C_2^{-1} \mathbf{D}^{-2} = 0 \tag{7}$$

Successive differentiation (" operation with $\mathbf{D}$ ") leads to the final differential equation obeyed by both branch currents

$$(m' R_1 R_2 \mathbf{D}^2 + g R_1 C_2^{-1} \mathbf{D} + C_1^{-1} C_2^{-1}) \ . \ i = 0 \tag{8}$$

which has a periodic and damped oscillatory solution

$$i = k e^{-\frac{\omega_0}{2Q} t} \cos(\omega_0 t + \phi) \tag{9}$$

if

$$g^2 R_1^2 C_2^{-2} < 4 m' R_1 R_2 C_1^{-1} C_2^{-1}$$

$$\text{or } g^2 \frac{R_1 C_1}{R_2 C_2} < 4m' \tag{10}$$

That means we get an oscillatory discharge of, say, an initial charge on the condeser C_1 with a frequency

$$\omega_0 = \frac{1}{\sqrt{m' R_1 R_2 C_1 C_2}} \tag{11}$$

depending on the valve constants and a damping depending on the Q of the circuit

$$Q = \frac{\sqrt{m'}}{g} \sqrt{\frac{R_2 C_2}{R_1 C_1}} \tag{12}$$

(the more usual notation for the exponential damping is

$$i = k e^{-2\delta \frac{t}{T}} \cos\left(2\pi \frac{t}{T} + \phi\right) \tag{9a}$$

where δ is the " logarithmic decrement." Comparing (9) and (9a) we have $\delta = \frac{\pi}{2Q}$ (9b)

It is clearly seen that the damping term in the differential equation is unaffected by the valve and the $\mathbf{D}^2$-term is greatly increased, in fact mainly given by the valve stage gain. If the valve is

removed from the circuit, $m=0$ and the value of m' is such that the inequality (10) is not fulfilled.* Then, as in (1), $B^2 > 4AC$ and the circuit is aperiodic.

In the **inductive** circuit the reactance operators are given by $\mathbf{H}=L\mathbf{D}$ so that we obtain directly from (6) the final differential equation

$$(L_1L_2\mathbf{D}^2+gR_1L_2\mathbf{D}+m'R_1R_2)i=0 \qquad (13)$$

Here the $\mathbf{D}^0$ term is increased by the valve, but the damping term is again unaffected. For the frequency and damping of the oscillatory discharge we obtain

$$\omega_0=\sqrt{\frac{m'R_1R_2}{L_1L_2}} \qquad (14)$$

$$Q=\frac{\sqrt{m'}}{g}\sqrt{\frac{R_2L_1}{R_1L_2}} \qquad (15)$$

i.e. the frequency increases with increasing stage gain.

3.3 Resonant and Filter Properties of the circuits.

Resonant properties can be observed with the circuit Fig. 3a if a source of alternating voltage is connected to it. This can be done in various ways:

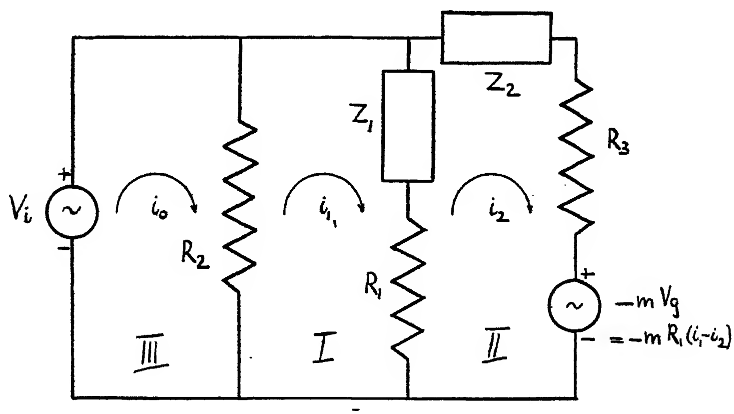


FIG. 4.

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* This follows easily from (5):—

$$g^2\frac{R_1C_1}{R_2C_2}>4\left(1+\frac{R_3}{R_2}+\frac{R_2}{R_1}+\frac{R_3}{R_1}+\frac{r_1}{R_1}+\frac{R_3r_1}{R_1R_2}+\frac{r_1r_2}{R_1R_2}+\frac{r_2}{R_1}+\frac{r_2}{R_2}=4\left(m'-m+\frac{R_2}{R_1}\right)\right.$$

using the general formula $(1+a+b+c+\ldots)^2>4(a+b+c+\ldots)$

3.3.1 Parallel Resonance. With a generator connected in parallel to the resistance R_2 of Fig. 3a we observe the effect of parallel resonance, that means the impedance presented to the generator is equivalent to the impedance of a parallel LC circuit.

We have the scheme of Fig. 4 and obtain applying Kirchhoff's laws to the loops III, I, I+II (the loops I and II being identical with Fig. 3b

$$\begin{array}{l} \mathrm{III} \\ \\ \mathrm{I} \\ \\ \mathrm{I+II} \end{array} \quad \psi . \mathbf{I}_{012} \equiv \left\{ \begin{array}{ccc} R_2 & -R_2 & 0 \\ -R_2 & \cdot & \cdot \\ & \phi & \\ -R_2 & \cdot & \cdot \end{array} \right\} . \left\{ \begin{array}{c} i_0 \\ i_1 \\ i_2 \end{array} \right\} = \left\{ \begin{array}{c} V_i \\ 0 \\ 0 \end{array} \right\} \quad (16)$$

$$\text{hence } i_0 = \frac{|\phi|}{|\psi|} V_i \qquad (17)$$

Calling the impedance presented to the generator " parallel impedance " Z_p we have

$$Z_p = \frac{V_i}{i_0} = \frac{|\psi|}{|\phi|} \qquad (18)$$

Expanding the numerator of (18) in terms of the reactance operators and simplifying

$$|\psi| = R_2 (\mathbf{H}_1\mathbf{H}_2 + hm'R_1R_2 + kgR_1\mathbf{H}_2) \qquad (19)$$

$$\text{where } h = \frac{1}{m'}\left(\frac{R_3}{R_2} + \frac{r_1R_3}{R_1R_2} + \frac{r_2}{R_2} + \frac{r_1r_2}{R_1R_2}\right) \text{(in practice negligible)} \quad (19a)$$

$$\text{and } k = \frac{1}{g}\left[1 + \frac{r_1}{R_1} + \frac{H_1}{H_2}\left(\frac{R_3}{R_1} + \frac{r_2}{R_1}\right)\right] \text{ (in practice } \approx \frac{1}{g}) \quad (19b)$$

so that with (6) we get the following general expression for the parallel impedance:

$$Z_p = R_2 \frac{\mathbf{H}_1\mathbf{H}_2 + hm'R_1R_2 + kgR_1\mathbf{H}_2}{m'R_1R_2 + gR_1\mathbf{H}_2 + \mathbf{H}_1\mathbf{H}_2} \qquad (20)$$

For the **capacitive** circuit we put now for the reactance operator $\mathbf{H} = \frac{-j}{\omega C}$ (and it is to be noted that the r's represent the equivalent series loss resistances given in terms of the condenser leakage resistances R_L by $r = (\omega C)^{-2} R_L^{-1}$). So we obtain from (20) for the complex impedance

$$Z_p = R_2 \frac{-1 + h\omega^2 m^1 R_1R_2C_1C_2 - j\omega kgR_1C_1}{\omega^2 m^1 R_1R_2C_1C_2 - 1 - j\omega gR_1C_1} \qquad (21)$$

which with (11) and (12) becomes

$$Z_p = R_2 \frac{1 - h\frac{\omega^2}{\omega_0^2} + j\frac{\omega}{\omega_0}\frac{k}{Q}}{1 - \frac{\omega^2}{\omega_0^2} + j\frac{\omega}{\omega_0}\frac{1}{Q}} \qquad (22)$$

i.e. there is resonance at the oscillation frequency of the free circuit and the selectivity factor Q determining the sharpness of resonance is the same as the Q determining the damping of the free circuit.

Writing γ for the relative frequency $\frac{\omega}{\omega_0}$, and representing the typical resonance function by **Res**(γ, Q) i.e.

$$\mathbf{Res}(\gamma,Q)\equiv(1-\gamma^2)^2Q^2+\gamma^2,$$

we obtain for the effective impedance $|Z_p|$, the phase angle ϕ_p, and for the resistive and reactive compounds, R_p and X_p, of Z_p compared with the corresponding expressions for a conventional LC circuit:

RC-CIRCUIT.

$$|Z_p|=R_2Q[1\cdot(1-h\gamma^2)^2+\gamma^2\frac{k^2}{Q^2}]^{\frac{1}{2}}\,\mathbf{Res}^{-\frac{1}{2}}(\gamma,Q)^*\quad(23)$$

$$\phi_p=\tan^{-1}\left[-\frac{\gamma(1-k)+\gamma^3(k-h)}{Q(1-\gamma^2)(1-h\gamma^2)+\gamma^2\frac{k}{Q}}\right]\quad(24)$$

$$R_p=R_2Q\,[Q(1-\gamma^2)(1-h\gamma^2)+\gamma^2\frac{k}{Q}]\,\mathbf{Res}^{-1}(\gamma,Q)\quad(25)$$

$$X_p=-R_2Q[\gamma(1-k)+\gamma^3(k-h]\mathbf{Res}^{-1}(\gamma,Q)\quad(26)$$

LC-CIRCUIT.

$$|Z_p|=\omega_0LQ(\gamma^2+\frac{1}{Q^2})^{\frac{1}{2}}\mathbf{Res}^{-\frac{1}{2}}(\gamma,Q)\quad(23a)$$

$$\phi_p=\tan^{-1}[\gamma(1-\gamma^2)-\frac{1}{Q}\gamma]\quad(24a)$$

$$Rp=\omega_0LQ\mathbf{Res}^{-1}(\gamma,Q)\quad(25a)$$

$$Xp=\omega_0LQ[\gamma(1-\gamma^2)-\frac{1}{Q}\gamma]\,\mathbf{Res}^{-1}(\gamma,Q)\quad(26a)$$

In the **inductive** circuit we have $\mathbf{H}=j\omega L$ and the complex impedance becomes

$$Z_p=R_2\frac{-1+\frac{hm'R_1R_2}{\omega^2L_1L_2}+\frac{j}{\omega}kg\frac{R_1}{L_1}}{\frac{m'R_2R_1}{\omega^2L_1L_2}-1+\frac{j}{\omega}g\frac{R_1}{L_1}}\quad(27)$$

Considering (14) and (15), we see that here again resonance occurs at the oscillation frequency of the free circuit. The corresponding expressions for $|Z_p|$ etc. have, apart from

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* In all the expressions (23)—(31) the practically irrelevant terms containing h have only been kept to show the effects at frequencies very far removed from resonance.

differences in sign, exactly the same appearance as those for the capacitive circuit if written in terms of the reciprocal relative frequency $\epsilon = \frac{\omega_0}{\omega}$

RL-CIRCUIT.

$$|Z_p| = R_2Q[1.(1-h\epsilon^2) + \epsilon^2\frac{k^2}{Q^2}]^{\frac{1}{2}} \,\mathbf{Res}^{-\frac{1}{2}}(\epsilon,Q) \qquad (28)$$

$$\phi_p = \tan^{-1}\left[\frac{\epsilon(1-k)+\epsilon^3(k-h)}{Q(1-\epsilon^2)(1-h\epsilon^2)+\epsilon^2\frac{k}{Q}}\right] \qquad (29)$$

$$R_p = R_2Q([Q1-\epsilon^2)(1-h\epsilon^2)+\epsilon^2\frac{k}{Q}]\,\mathbf{Res}^{-1}(\epsilon,Q) \qquad (30)$$

$$X_p = R_2Q[\epsilon(1-k)+\epsilon^3(k-h)]\,\mathbf{Res}^{-1}(\epsilon,Q) \qquad (31)$$

It is interesting to compare the results obtained with those for LC circuits in graphical representation. (For properties of LC-circuits see a recent survey by Sherman[18]). Fig. 5 shows the comparison of a parallel LC-circuit with a capacitive valve resonant circuit of the same resonance frequency and Q. In Fig. 5a the

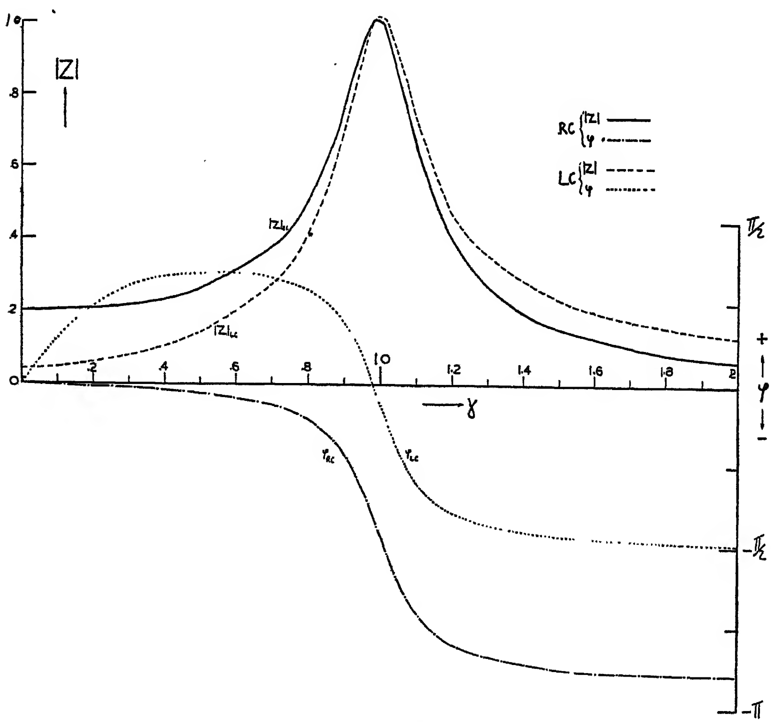

FIG. 5*a*.

modulus and phase angle of Z_p are shown. It is seen that the modulus has the same appearance in both cases. The phase angle curves are, however, quite different. In the LC circuit we have at resonance zero phase-angle, purely resistive impedance, in the valve circuit the resonance phase angle is $-90°$, the phase angle of a pure capacitance (and this is obtained across a resistance!)

Fig. 5b shows the resistive and reactive components of Z^p

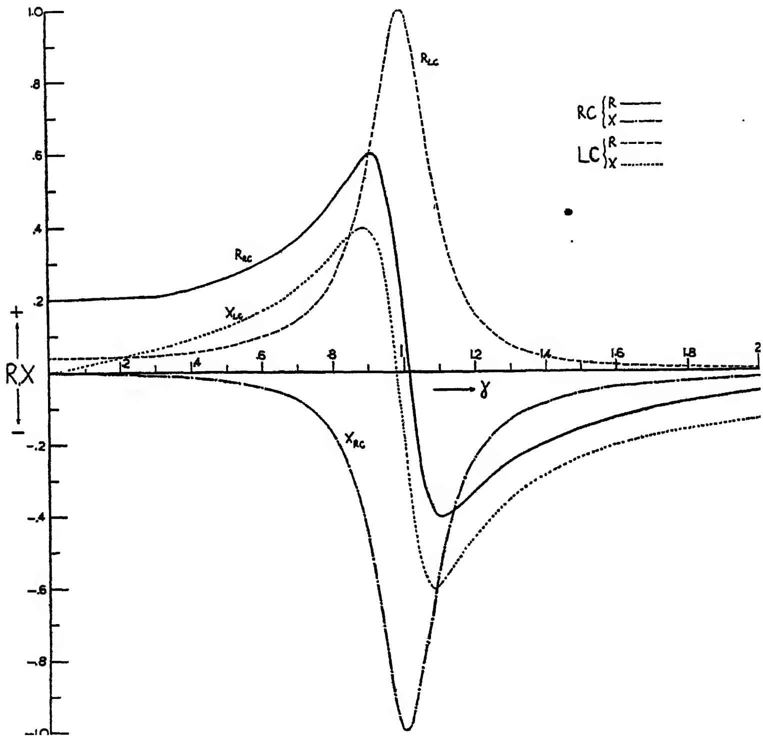

FIG. 5*b*.

separately. LC resonance is characterized by a maximum of the always positive resistive component and an S-shaped curve of the reactance against frequency with two maxima, one positive and one negative. In the valve circuit it is the reactive component which does not change sign and which has the maximum, whereas the resistive component changes sign at resonance, the resistance becoming negative at frequencies above resonance. This fact will be of importance for coupled resonant circuits to be considered below.

For the inductive circuit we get very similar pictures plotted against ϵ, but with the signs reversed, the resonance phase angle being $+90°$ and the reactive component always positive.

3.3.2 Series Resonance. If in the circuit of Fig. 3 a generator is connected in series with R_2, the impedance presented to the generator is of the series resonance type and will be called " series impedance " Z_s.

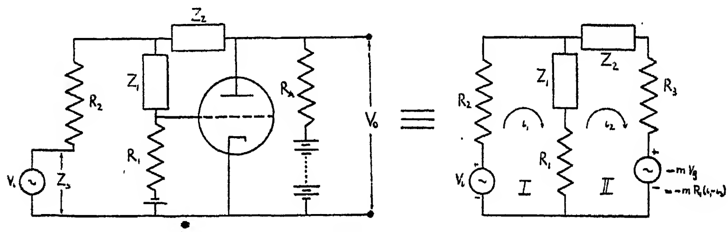

FIG 6.

We have the scheme Fig. 6 from which we obtain, using the loops I and I+II (as in the nearly identical scheme Fig. 3b)

$$\phi \cdot \mathbf{I}_{12} = \begin{pmatrix} V_i \\ V_i \end{pmatrix} \qquad (32)$$

hence
$$i_1 = \frac{\phi_{22} - \phi_{12}}{|\phi|} V_i \qquad (33)$$

The series impedance is given by

$$Z_s = \frac{V_i}{i_1} = \frac{|\phi|}{\phi_{22} - \phi_{12}} \qquad (34)$$

which, on comparison with (6), shows directly the resonance character.
Evaluating the denominator of (37) and simplifying

$$\phi_{22} - \phi_{12} = \frac{1}{R_2}\left(vm'R_1R_2 + w\sqrt{\frac{m'R_2H_1}{R_1H_2}}R_1\mathbf{H}_2\right) \qquad (35)$$

where

$$v = \frac{m}{m'} + \frac{1}{m'} + \frac{R_3}{m'R_1} + \frac{r_1 + r_2}{R_1 m'} \quad \text{(in practice equal to unity)} \qquad (36)$$

$$w = \sqrt{\frac{R_2}{m'R_1}}\left(\sqrt{\frac{H_1}{H_2}} + \sqrt{\frac{H_2}{H_1}}\right) \quad \text{(in practice negligible)} \qquad (37)$$

Using the same notation as in 3.3.1 we have finally for the **capacitive circuit** with (11) and (12) the complex series impedance

$$Z_s = -\frac{R_2}{Q}\,\frac{(1-\gamma^2)Q + j\gamma}{v\gamma^2 - jw\gamma} \qquad (38)$$

and the effective impedance $|Z_s|$ and phase angle ϕ_s

$$|Z_s| = \frac{R_2}{Q\epsilon}(v^2\gamma^2 + w^2)^{-\frac{1}{2}}\mathbf{Res}^{\frac{1}{2}}(\gamma, Q) \quad (39)$$

$$\phi_s = \tan^{-1}\left[\frac{-\gamma^2 - w(1-\gamma^2)Q}{-v\gamma Q(1-\gamma^2) + w\gamma}\right] \quad (40)$$

for the inductive circuit

$$|Z_s| = \frac{R_2}{Q\epsilon}(v^2\epsilon^2 + w^2)^{-\frac{1}{2}}\mathbf{Res}^{\frac{1}{2}}(\epsilon, Q) \quad (41)$$

$$\phi_s = \tan^{-1}\left[\frac{v\epsilon^2 + w(1-\epsilon^2)Q}{-v\epsilon Q(1-\epsilon^2) + w\epsilon}\right] \quad (42)$$

The expressions are seen to correspond to those holding in the case of LC series resonance, R_2 taking the place of $\omega_0 L$. But we get the same difference in the phase angle as in parallel resonance, the resonant phase angles being $-90°$ and $+90°$ respectively for the capacitive and inductive circuits.

3.3.3 Selective Amplification. Of greater practical importance than the pure resonance effects is the action of the valve circuits as selective and amplifying filters or " tuned amplifiers " using the output voltage between anode and earth of the valve produced by an alternating input connected as in Fig. 6. The selective amplification is expressed by the ratio of output voltage V_0 to generator or input voltage V_i in magnitude and phase angle. Using the scheme Fig. 6 and equation (32) we obtain

$$i_2 = \frac{\phi_{11} - \phi_{21}}{|\phi|}V_i \quad (43)$$

Since the output voltage is given by

$$V_0 = R_3 i_2 - mVg = R_3 i_2 - mR_1(i_1 - i_2) =$$
$$[(R_3 + mR_1)(\phi_{11} - \phi_{21}) - mR_1(\phi_{22} - \phi_{12})]\frac{Vi}{|\phi|} \quad (44)$$

we get for the selective amplification

$$\frac{V_0}{Vi} = m'f\frac{-gR_1\mathbf{H}_2 + \frac{bg}{\sqrt{m'}}\sqrt{\frac{H_2R_1}{H_1R_2}}}{m'R_1R_2 + gR_1\mathbf{H}_2 + \mathbf{H}_1\mathbf{H}_2} \quad (45)$$

where $f = \frac{1}{g}\left(\frac{m}{m'} - \frac{H_1}{H_2}\frac{R_3}{R_1}\frac{1}{m'}\right)$ (essentially equal to $\frac{1}{g}$) (46)

$$b = \frac{1}{fg\sqrt{m'^3}}\sqrt{\frac{H_1R_2}{H_2R_1}}\left(\frac{R_3}{R_2} + \frac{R_3r_1}{R_1R_2} - \frac{mr_2}{R_2}\right) \text{ (negligible if } m \gg 1) \quad (47)$$

Hence for the **capacitive circuit**

$$\frac{V_0}{Vi} = m'f\,\gamma\,\frac{-j - b\gamma}{(1-\gamma^2)Q + j\gamma} \qquad (48)$$

$$\left|\frac{V_0}{Vi}\right| = m'f\gamma\,(1+b^2\gamma^2)^{\frac{1}{2}}\ \mathbf{Res}^{-\frac{1}{2}}(\gamma, Q) \qquad (49)$$

$$\phi = \tan^{-1}\frac{-Q(1-\gamma^2) + b\gamma}{-\gamma - b\gamma Q(1-\gamma^2)} \qquad (50)$$

and for the **inductive circuit**

$$\frac{V_0}{Vi} = m'f\,\epsilon\,\frac{j - b\epsilon}{(1-\epsilon^2)Q - j\epsilon} \qquad (51)$$

$$\left|\frac{V_0}{Vi}\right| = m'f\,\epsilon\,(1+b^2\epsilon^2)^{\frac{1}{2}}\ \mathbf{Res}^{-\frac{1}{2}}(\epsilon, Q) \qquad (52)$$

$$\phi = \tan^{-1}\frac{Q(1-\epsilon^2) - b\epsilon}{\epsilon - b\epsilon Q(1-\epsilon^2)} \qquad (53)$$

The amplification is a maximum at resonance ($\left|\frac{V_0}{V_i}\right|_{res}$ given by $m'f \approx \frac{m'}{g}$) nearly equal to the valve stage gain, and the phase angle here being 180° as in an ordinary amplifier or in a LC tuned amplifier at resonance.

3.4 Resonance Frequency

The resonance or tuning frequency in all treated cases is given by the expressions (11) and (14). The appearance of the valve stage gain m in these expressions is useful in so far as it allows low frequency resonance to be obtained using not excessively low condensers, and high frequency resonance using not excessively low inductances. The drawback of the appearance of the valve constants in the frequency expressions with regard to frequency stability can be overcome by using valve combinations (see footnote p. 402) and stabilizing the overall gain by negative feedback.

3.5. The Selectivity Q

The sharpness of resonance or tuning is in all cases given by the equations for Q (12) and (15), increasing as one would expect with the valve stage gain. The Q of LC circuits depends directly on the ratio of reactance to resistance in the reactor. A change in resonance frequency in a given circuit by variation of the capacitance is therefore accompanied by a change in Q, and low resonance frequencies cannot be obtained as outlined above. In the present circuits the loss resistances enter the expression for Q only very indirectly (through g, and are negligible in the

capacitive circuit) and Q depends mainly on resistance and reactance **ratios.** The resonance frequency can therefore be varied and the Q kept at the same high value.

For the capacitive circuit we find in particular that there is no limitation to the obtainable resonance frequency on the low frequency side. As long as the ratio $g^2 \frac{R_1C_1}{R_2C_2}$ is kept small, the individual values of the resistances can be made very high and the resonance frequency extremely low. Resonance of sufficient sharpness, i.e., Q of the order of 5 to 10, can be obtained with ease at frequencies round 1 c.p.s. or even smaller.

At radio frequencies where the inductive circuit is feasible, a Q of this order is rather low. It will, however, be possible to increase the high selectivity of LC circuits in this frequency range by **combining** them with the new inductive valve resonant circuits.

3.6. Optimum Selectivity.

The Q depends in a rather involved way on the various resistance and reactance ratios. It is of interest to determine for one practical case the optimum value for these ratios, i.e., the value which gives maximum Q.

For a given valve or valve arrangement the valve amplification m and effective resistance R_3 are given. The grid resistance R_1 should be as high as is compatible with the conditions to make g small and Q high. It will be limited by grid cathode leakage and input capacity. Assuming R_1 to be fixed we have to determine the optimum values of the ratios $e = \frac{R_2}{R_1}$ and $a = \frac{H_1}{H_2}$ in terms of the ratio $c = \frac{R_3}{R_2}$ and of the loss ratios $\alpha_1 = \frac{r_1}{R_1}$; $\alpha_2 = \frac{r_2}{R_1}$, i.e., the values of c and a which make Q a maximum or $\frac{m'}{Q^2}$ a minimum.

We obtain from (12), (15) and (5)

$$\frac{m'}{Q^2} = \frac{R_1}{R_2}\frac{H_2}{H_1}g^2, = \eta(a,e) = \frac{1}{ae}[1+e+\alpha_1+a(e+c+\alpha_2)]^2 = \text{minimum} \tag{53}$$

solving $\frac{\delta\eta}{\delta a} = 0$; $\frac{\delta\eta}{\delta e} = 0$ gives the optimum values:

$$e_{opt} = \sqrt{(c+\alpha_2)(1+\alpha_1)}$$
$$a_{opt} = \sqrt{1+\alpha_1}/\sqrt{c+\alpha_2} \tag{54}$$

The maximum value of Q under these conditions is

$$Q_{max} = \tfrac{1}{2}\sqrt{m^1}(\sqrt{1+\alpha_1}+\sqrt{+c+\alpha_2})^{-\frac{1}{2}} \tag{55}$$

If the losses are negligible, we have

$$e_{opt} = \sqrt{c} \quad a_{opt} = \frac{1}{\sqrt{c}} \qquad Q_{max} = \tfrac{1}{2}\sqrt{m^1}\,(1+\sqrt{c})^{-1} \qquad (56)$$

And the absolute maximum of Q is obtained if $c \rightarrow 0$

$$Q_{max} \rightarrow \tfrac{1}{2}\sqrt{m^1}$$

§4. EXPERIMENTAL WORK.

In order to illustrate the theoretical results of the preceding section some experimental curves are reproduced.

4.1. Apparatus.

The curves obtained with the arrangement shown in Fig. 7 L.F.O. is a variable low frequency oscillator (2-16 cps.) of special design (incorporating capacitive valve resonant circuits, see §5 below). Its output was checked by the vertical deflection of the cathode ray oscilloscope C.R.O.1 (Ultrascope). 1 second periodic pulses derived from an electric clock* and fed to the X-plates

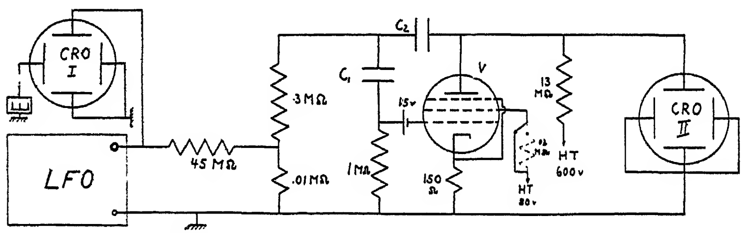

FIG. 7.

of the oscilloscope served to check the frequency of the oscillations by counting the coincidences (a very convenient and speedy method of frequency measurement). The oscillator output is connected, through a potentiometer arrangement, R_4 R_5, in "series" with the capacitive valve resonant circuit $R_1R_2C_1C_2V$. The valve used is a Mullard SP4 pentode. The biassing arrangement produces some negative feedback ensuring a certain amount of stabilization. The output from the valve was measured with a second calibrated oscilloscope C.R.O.2, the vertical deflection being measured with a ruler. This was found to be the most satisfactory method for the frequencies used since ordinary valve voltmeters are not suitable for very low frequencies and ordinary voltmeters (moving coil, etc.) are only suitable for

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* "Gent's" electrically maintained pendulum clock in the Electrical Engineering Department of this College. I am indebted to Professor J. C. Prescott for permission to use the clock and to make the necessary electric connections to the Physics Department.

frequencies far removed from their natural mechanical vibration frequency. The stage gain m of the valve was measured by disconnecting the control grid from the circuit, connecting it to a known fraction of the mains alternating voltage and observing the output deflection. The resistance R_6(.03 M) could be inserted in series with the screen grid to reduce the stage gain without appreciably changing the effective output resistance R_3. The latter is mainly determined by the anode load R_A (0.13 M Ω) slightly reduced by the internal valve resistance and input resistance of the Ultrascope. The latter was found to be as low as 0.9 MΩ. The values of the circuit components in all experiments shown here were as follows:

$R=1.0_5 M\Omega$ $\qquad$ $R=0.095 M\Omega$

$R=0.31_7 M\Omega$ $\qquad$ $C_2/C_1=3$

so that from (5) we have for the damping factor (neglecting condenser losses) $g=2.5_4$.

4.2 Selective Amplification Curves.

Measuring the output as a function of the oscillator frequency gives selective amplification curves. Fig. 8 shows curves with the same capacitances $C_2=3\times C_1=.015\ \mu F$, for two different values of the stage gain m to demonstrate its influence on the

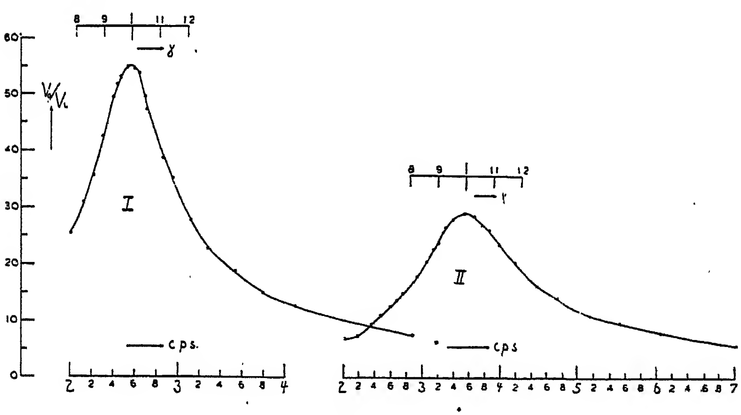

FIG. 8.

resonant frequency and selectivity Q. For curve I: m=145. From the experimental curve we find $f_0=2.5_8$ cps, Q=4.37 and $|V_0/V|_{res}=54._7$. This agrees satisfactorily with the values calculated from (11), (12), (49): $f_0=2.6_2$ cps, Q=54.6, and $\left|\frac{V_0}{Vi}\right|_{res}=57._0$. For curve II $m=77._6$ the resonant frequency is higher, the selectivity* and maximum amplification smaller,

* In all graphs the frequencies are plotted in such a way that the relative frequency scale is the same for all curves.

we find experimentally: $f_0 = 3.5_6$ cps, $Q = 3.3_0$, $\left|\frac{V_0}{Vi}\right|_{res} = 29._4$,

and by calculation: $f_0 = 3.5_8$ cps, $Q = 3.3_8$. $\left|\frac{V_0}{Vi}\right|_{res} = 30._5$.

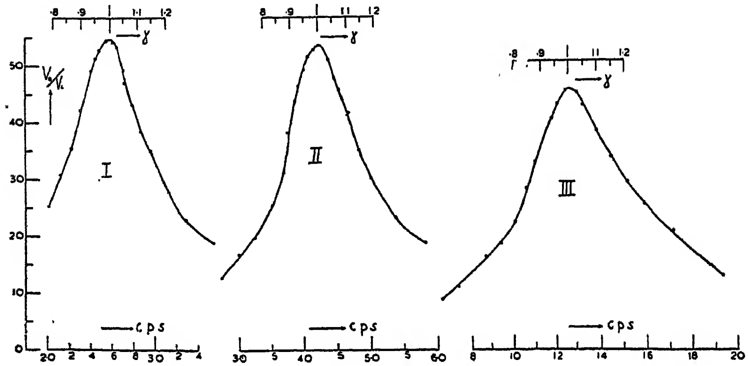

FIG. 9.

In Fig. 9 curves for three different pairs of capacitances are reproduced to show the possibilities of the new circuit at fixed stage gain, $m = 145$. Curve I was the lowest resonance curve obtainable with the available oscillator, but it is far from the low frequency limit of the circuit; the capacitances could easily be increased by a factor 100 giving resonance at .02 cps (1 vibration per 50 secs!). For curve I, which is identical with curve I Fig. 8, $C_2 = 3 \times C_1 = .015\,\mu F$, $f_0 = 2.5_8$, $Q = 4.37$ $\left|\frac{V_0}{Vi}\right| = 54._7$. For curve II $C_2 = 3 \times C_1 = .009\,\mu F$, $f_{0\,exp} = 4.2_1$ cps, $f_{0\,calc.} = 4.3_6$ cps, and we see that the experimental values for Q and $\left|\frac{V_0}{Vi}\right|_{res}$ 4.3_4 and $54._0$ respectively, are near enough the same as for the lower frequency and the calculated values, confirming that the resonant frequency can be changed without affecting the selectivity. This change can cover a very wide range provided the capacitances are loss free. In the arrangement here this is not quite the case, for curve III $C_2 = 3 \times C_1 = .003\,\mu F$, $f_{0exp} = 12.5$ cps, $f_{0\,calc.} = 13._1$ cps in satisfactory agreement but both the $Q = 3.6_0$ and $\left|\frac{V_0}{Vi}\right|_{max} = 46._5$ are found to be smaller than the previous values indicating an increased damping factor g due to the loss resistances r_1 r_2 being no longer negligible. The capacitances used are decade mica condenser boxes which,

particularly for the low capacity values, are bound to have some losses. For higher frequency resonance, therefore, either more nearly perfect condensers would have to be used or alternatively lower values of the resistances R_1 R_2 (as far as is compatible with a small ratio $\frac{R_3}{R_1}$) requiring greater capacitances for the same frequencies and so reducing the condenser losses (see p. 9).

It is to be noted that in the arrangement with the high resistance values the capacities required for resonance below 10 cps are very small. Ordinary continuously variable rotating condensers could be used with only a few steps of fixed condensers to cover a wide range of frequencies down to 2 cps or lower. This fact will be useful for low frequency analyzers, e.g., for biological purposes (encephalography[19,20]), etc., and is due to the fact that the stage gain appears in the frequency expression. The advantage gained by increasing m through the use of valve combinations in place of a single valve is therefore twofold: higher selectivity and lower capacity.

4.3 Frequency Analysis.

In order to demonstrate the usefulness and limitations of the simple experimental circuit for the purpose of analyzing a complex wave the response to a periodic voltage of saw-tooth form was investigated:

The periodic pulses from the clock were used to trigger a simple saw-tooth generator consisting of the resistance-capacitance combination RC and the thyratron valve Th, see Fig. 10. The

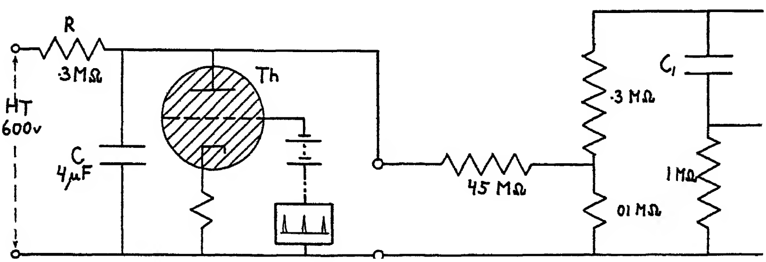

FIG. 10.

saw-tooth wave obtained, of frequency exactly 1 sec., formed the input to the valve resonant circuit. Measuring the output of the latter for varying values of the capacitances determining the tuning frequency (keeping always $C_2/C_1=3$) gave a curve, reproduced in Fig. 11, which represents the analysis of the complex input. The fundamental, second, and third harmonic can be recognised. There is a faint indication of the fourth harmonic,

but it is almost completely drowned in the background, produced by the contribution of all harmonics, particularly all the higher ones to the output.

This drowning effect shows the limitation of the circuit, it is clearly the more marked the lower the Q. It follows from equation

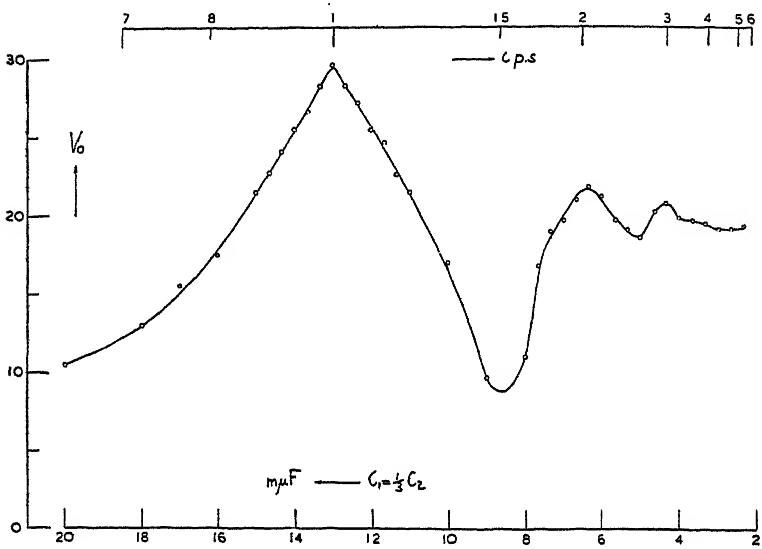

FIG. 11.

(49) that for frequencies far above resonance the output is approximately $\frac{1}{\gamma Q}$ of the resonance output (for extremely high γ's the term in (49) containing b makes this fraction still greater). Since the amplitude of the n-th harmonic of a saw-tooth voltage of tooth height H is given by $A_n = \frac{H}{n\pi}$, it is easily seen that with a Q of only 4.5 the background must be an appreciable fraction of even the fundamental output. For periodic pulses of short duration the situation would be still worse, the fundamental and all the early harmonics being equal and small ($A_n \cong \frac{H}{\pi} \frac{\tau}{T}$ if T period and τ pulse duration) so that hardly anything would emerge from the background. However, for the analysis of waves containing a small number of low- or non-multiple frequencies the selectivity obtainable with the simple circuits should be sufficient.

§5. COUPLED CIRCUITS.

5.1 Methods and Effects of Coupling.

The peculiar form of the input part of the new resonant circuit with its input resistance R_2 is most suitable for coupling the circuits together or to ordinary non-selective amplifiers. The coupling can be effected through resistances only, no additional capacitances being required to separate d.c. and a.c. paths, a very useful feature for low frequency purposes.

5.1.1 Coupling to ordinary amplifier. Fig. 12 shows how an ordinary amplifier can be coupled to a valve resonant circuit. The anode load of the amplifier acts as part of the input resistance

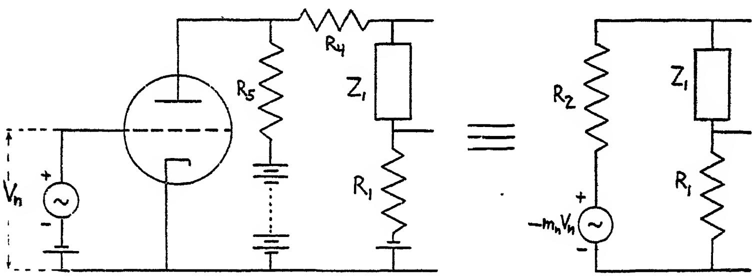

FIG. 12.

of the resonant circuit and the action of the combination is equivalent to a single resonant circuit with input voltage $m_n V_n$ (where m_n is the stage gain of the non-selective amplifier) and input resistance $R_2 = R_4 + \frac{R_5 P_n}{R_5 + P_n}$ (P_n = impedance of input valve.

This arrangement will be convenient if only a small voltage is available for analysis and the fact that a very high impedance (grid-cathode impedance of input valve) is presented to the voltage to be analysed, is a further advantage.

5.1.2 Intercoupling Resonant Circuits. Fig. 13 gives the coupling element between two valve resonant circuits. The resistance R_7 is part of the load of circuit 1 as well as part of the input resistance of circuit 2. The ratio $k = \frac{R_7}{R_7 + R_8}$ determines the closeness of coupling.

The case where two resonant circuits tuned to the same frequency are closely coupled is of particular interest. Typical coupling phenomena are observed. The over-all response of the two coupled circuits is similar to that of two coupled LC circuits showing the characteristic splitting up of the single peak,

coresponding to the individual or loosely coupled circuits, into two peaks on both sides of it. In Fig. 14 an experimental curve is reproduced showing this effect. The curve gives the overall response of two identical coupled capacitive circuits using pentodes and having individual selectivities $Q=5$. The values of the coupling resistances were $R_7=.15M\,\Omega$, $R_8=.46M\Omega$, $R_6=.5M\,\Omega$, so that $K=2.4_6$. The dotted line gives the relative response curve of the individual circuits.

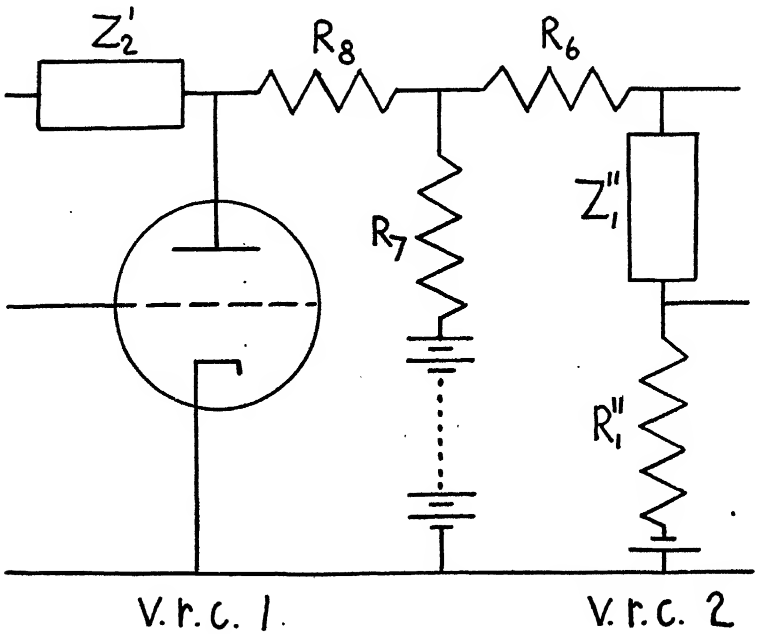

FIG. 13.

A quantitative analysis of these coupling effects would be very complicated and would hardly serve a useful purpose. A qualitative understanding, however, is obtained if it is realised that part of the parallel impedance Z_P of circuit 2 forms part of the load impedance of circuit 1. Consequently, since Z_P depends on frequency and has a reactive component, the stage gain m, of circuit 1 depends on frequency and has a reactive component. The " coupled " resonant frequency and selectivity vary therefore with frequency. In particular at the resonant frequency of the individual circuits Z_P is purely reactive (see p. 10) and hence

the reactive component of m_1 will there be a maximum. This reactive part leads to an increase in the damping factor g*, hence producing a reduction in the amplification of circuit 1 corresponding to the depression in the coupling curve. At frequencies above and below the individual resonance the resistive component of Z_P will be of influence. Below resonance the resistive component of Z_P is positive, the resistive component of the load of valve 1 is therefore increased, producing an increase in m and shifting

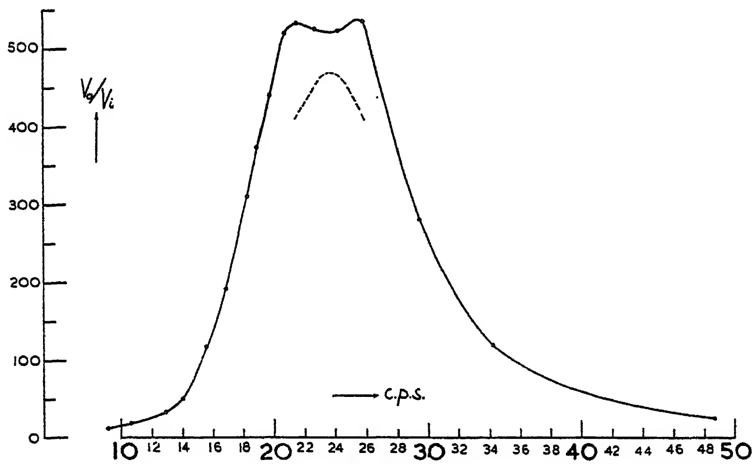

FIG. 14.

the "coupled" resonance of circuit 1 to lower frequencies. The low frequency peak of the coupling curve will therefore lie somewhere near the frequency of the positive maximum of the resistive component of Z_P. Similarly for the high frequency peak of the coupling curve. Here the resistive component of Z_P is negative, m_1 is reduced and the "coupled" resonance of circuit 1 shifted to higher frequencies.

These coupling effects can be made use of to obtain with closely coupled capacitive circuits tuned to the same or slightly different frequencies band pass filters for very low frequencies which may have applications in sound reproduction and in the television field.

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* This is easily seen from equations (3) and (5) p. 7: the reactive component $\mathbf{H}_m$ of m_1 leads to an additional term $\mathbf{H}_m R_1 R_2$ in (3) and hence $\frac{H_m}{H_2}$ R_2 in (5). Since $\mathbf{H}_m$ is of the same reactive type as $\mathbf{H}_2$ this additional term in g is positive.

On the other hand using two capacitive circuits loosely coupled in succession and coupling the output of the second loosely back to the input of the first an oscillator is obtained. This is the basis of the oscillator used in the experiments described in §4.

5.2. Highly Selective Analyzer.

Another application of the new circuits in the coupled form lies in more complex low frequency analyzers of extreme selectivity. As mentioned above the Q which can be reached with one single circuit is of the order of 10. This is not sufficient for some purposes. But it is possible to reach selectivities of a much higher order by using the capacitive valve resonant circuit in the feedback path of a selective negative feedback amplifier (the method of low frequency analysis by selective negative feedback is due to H. H. SCOTT[21]). An instrument of this type suitable for frequencies from 1-15 cps has been built and will be described in detail elesewhere. Selectivities of the order $Q = 150$ were reached corresponding to a possible frequency discrimination of about 0.1%. This seems an important advance and may find useful applications in physical and technical measurements.

§6. OSCILLATORS.

One of the main points of the single resonant circuits described so far is their stability. Certain alterations of the simple circuit lead to the production of self oscillations and these oscillators are deemed to be of sufficient interest to warrant a brief description.

6.1. Screengrid Oscillator.

One way of making the original circuit oscillatory consists in using a tetrode or pentode and including in the screen circuit a reactance of the same type as in the main circuit (see Fig. 15). The reason for its working is that we have now instead of a simple voltage amplification an amplification having a reactive component of suitable sign, i.e., the output voltage is out of antiphase with the control grid voltage.

The quantitative relations can be obtained by first considering the general case of a valve having load impedances Z_A and Z_s in the anode and screen circuits respectively. The anode and screen currents, i_A and i_s respectively, are functions of the control grid, screen grid, and anode voltages, v_g, v_s, and v_A respectively. By Taylor's theorem we have for alternating components (denoted by capitals) if the valve is operated in a small, nearly linear, range:

$$
\begin{aligned}
I_A &= \frac{\delta i_A}{\delta v_g} V_g + \frac{\delta i_A}{\delta v_s} V_s + \frac{\delta i_A}{\delta v_A} V_A \\
I_s &= \frac{\delta i_s}{\delta v_g} V_g + \frac{\delta i_s}{\delta v_s} V_s + \frac{\delta i_s}{\delta v_A} V_A
\end{aligned}
\qquad (58)
$$

the differentials are the valve parameters defined as follows:

$$\frac{\delta i_A}{\delta vg} = g_A \;=\; \text{the \textbf{anode} to control-grid transconductance.}$$

$$\frac{\delta i_A}{\delta v_S} = \gamma_A \;=\; \text{the \textbf{anode} to screen-grid transconductance.}$$

$$\frac{1}{\dfrac{\delta i_A}{\delta v_A}} = \rho_A \;=\; \text{the internal \textbf{anode} impedance.}$$

$$\frac{\delta i_S}{\delta vg} = g_S \;=\; \text{the \textbf{screen-grid} to control-grid transconductance.}$$

$$\frac{\delta i_S}{\delta v_A} = \gamma_S \;=\; \text{the \textbf{screen-grid} to anode transconductance.}$$

$$\frac{1}{\dfrac{\delta i_S}{\delta v_S}} = \rho_S \;=\; \text{the internal screen-grid impedance.}$$

(g_A , ρ_A are the only parameters which are of interest in conventional problems.)

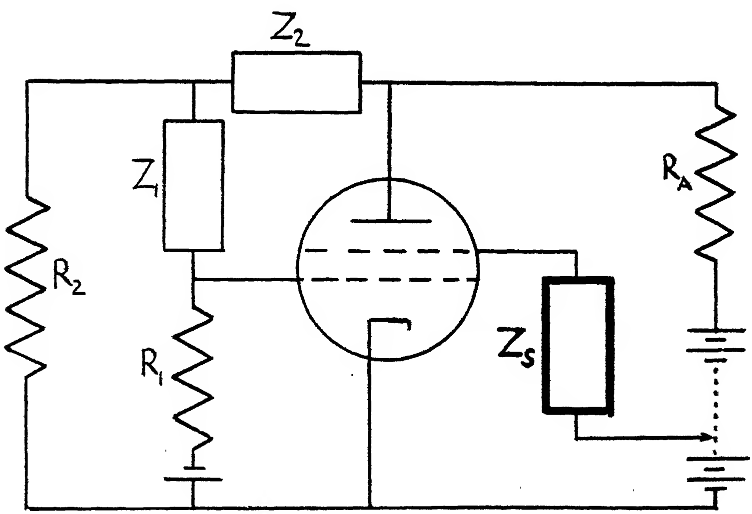

FIG. 15.

With this notation and the relations $V_A = -I_A \cdot Z_A, V_S = -I_S \cdot Z_S$ (58) becomes

$$\Gamma_{AS} \equiv \begin{Bmatrix} \rho_A + Z_A & \rho_A \gamma_A Z_S \\ \rho_S \gamma_S Z_A & \rho_S + Z_S \end{Bmatrix} \begin{Bmatrix} I_A \\ I_S \end{Bmatrix} = \begin{Bmatrix} g_A \rho_A V_g \\ g_S \rho_S V_g \end{Bmatrix} \quad (59)$$

from which we find

$$I_A = \frac{\begin{vmatrix} \rho_A g_A & \rho_A \gamma_A Z_S \\ \rho_S g_S Z_A & Z_S \end{vmatrix}}{|\Gamma|} V_g \quad (60)$$

and the voltage amplification

$$\frac{V_A}{V_g} = -\frac{I_A Z_A}{V_g} = -\frac{g_A \rho_A - \gamma_A \rho_A g_S \rho_S \dfrac{Z_S}{\rho_S + Z_S}}{\rho_A + Z_A - \gamma_S \gamma_A \rho_A \rho_S \dfrac{Z_S}{\rho_S + Z_S} Z_A} . Z_A \quad (61)$$

Assuming now that the anode load is purely resistive, $Z_A = R_A$ and the screen load, $Z_S = \mathbf{H}_S + r_S$, mainly reactive its effective value small against ρ_S, and considering the fact that in all valves γ_S, the change of screen current with anode voltage is very small (negative) against the other valve constants, (61) simplifies to

$$\frac{V_A}{V_g} = -\left(\frac{\rho_A R_A}{\rho_A + R_A} g_A - \frac{\rho_A R_A}{\rho_A + R_A} g_S \gamma_A \mathbf{H}_S\right) \equiv -(M - N\mathbf{H}_S)$$

$$N \equiv M\gamma_A \frac{g_S}{g_A} \quad (62)$$

where M is the stage gain of the valve without screen load and N (of the dimension of a conductance) is the coefficient of the additional reactive term.

For the analysis of the whole oscillating circuit Fig. 15 we have then simply to replace m in equations (2), (3), (5), (6) everywhere by $(M - N\mathbf{H}_S)$. This leads to the following additional term in (3):

$$-NR_1R_2\mathbf{H}_S$$

so that the new damping factor becomes

$$g' = g - NR_2 \frac{H_S}{H_2} \quad (63)$$

That means we get a negative contribution to the damping term in the differential equation (6) if $N \dfrac{H_S}{H_2}$ is positive or since N is always positive, if the screen reactance is of the same type as the reactance in the main circuit, capacitive in a capacitive resonant circuit, inductive in an inductive circuit. Oscillations

occur if the damping term vanishes, hence the maintenance condition:

$$R_2 N \frac{H_s}{H_2} \geqq g \qquad (64)$$

It is obvious that the "maintenance" condition in oscillators is only a limiting condition. If oscillations of finite amplitude are produced, the damping term of the differential equation must be negative during part of the cycle of the oscillations. The circuit must, therefore, contain a non-linear element acting in such a way that in the steady state the average of the damping factor during one cycle is zero. This condition for finite oscillations can be written:

$$\int_0^{\frac{2\pi}{\omega}} g' dt = 0 \quad \text{or} \quad \frac{\omega}{2\pi} R_2 \frac{H_s}{H_2} \int_0^{\frac{2\pi}{\omega}} M \gamma_A \frac{g_s}{g_A} dt = g \qquad (65)$$

The required non-linearity gives rise to harmonic distortion in the produced oscillations (obviously increasing with amplitude). In LC oscillators and other RC oscillators the harmonic distortion is rather high because the non-linearity affects not only the damping term but at least one of the other terms of the corresponding differential equation as well. In the screen grid oscillator described here the valve can be so operated that there is non-linearity only with respect to the screen current, i.e., M not depending on the amplitude. Then only the damping term of the differential equation is affected by the non-linearity and we would expect extremely small harmonic distortion even at greater amplitudes. This has been confirmed by measurements (to be described elsewhere).

6.2. Grid Impedance Oscillator.

A negative term in the damping factor and oscillations can also be produced by introducing a reactive component, of opposite type to that of the main circuit, in any of the three main resistances, R_1, R_2, or R_3.

Taking the grid resistance R_1 for this purpose we connect in parallel with it an impedance $Z_G = (\mathbf{H}_G + r_G)$ of high reactance, $|H_G| \gg R_1$, see Fig. 16. The parallel combination of R_1 and Z_G is then equivalent to R_1 with a reactive component $\frac{R_1^2}{\mathbf{H}_G}$ in series. Hence we can again use equations (3), (5), (6) for the analysis replacing everywhere R_1 by $R+\frac{R_1^2}{\mathbf{H}_G}$. This leads to several additional terms in (3) of which only the one containing m is relevant: $mR_2R_1^2/\mathbf{H}_G$, so that the new damping factor becomes:

$$g' = g + m \frac{R_1 R_2}{H_2 H_G} \qquad (66)$$

The additional term is negative, leading to reduction of g and oscillations, if the parallel grid reactance is of opposite type to the main circuit reactance, e.g., capacitive in an inductive resonant circuit. We have then $H_2H_G = -\frac{L_G}{C_2}$ or $-\frac{L_2}{C_G}$ so that the maintenance condition can be written:

$$m\, R_1 R_2 \frac{L_{G(2)}}{C_{2(G)}} = g \tag{67}$$

Here the non-linearity must be in the m, which means that it affects also the $\mathbf{D}^2$ or $\mathbf{D}^0$ term of the differential equation and the distortion will not be especially low.

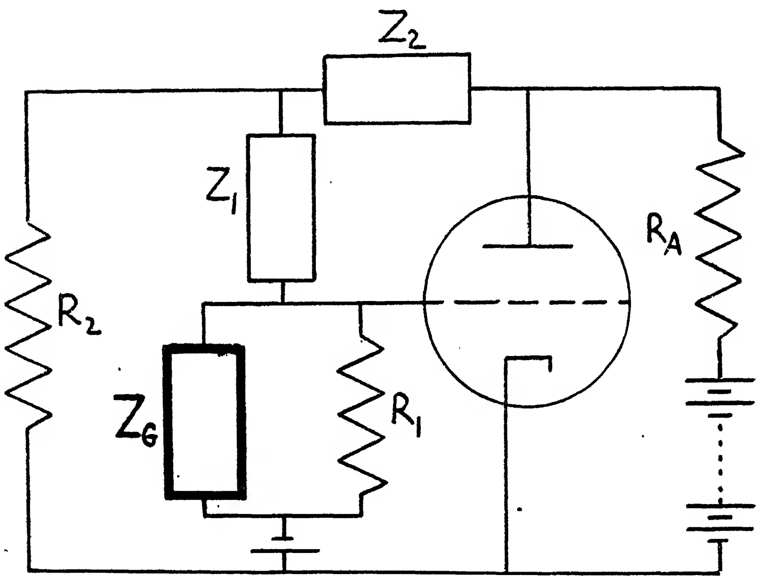

FIG. 16.

The circuit is, however, of importance in the inductive case where the parallel grid impedance can be supplied by the interelectrode grid-cathode capacity of the valve.

6.3. Frequency Variation of Oscillators and Frequency Modulation.

In these and other types of oscillators which can be developed from the simple circuit, the oscillation frequency is given by the resonant frequency of the original circuit. It is of special significance that the frequency can be varied without changing the amplitude of the oscillations. In the screen impedance oscillator, for instance, the frequency can be changed by varying

R_1 without affecting the amplitude since the maintenance condition does not depend on R_1 (provided R_1 is large compared with R_2 and R_3, thus minimizing the indirect effect on g).

This fact leads to the idea of using the new circuits as the basis for frequency modulated oscillators. The frequency variation could be effected by replacing one (or more) of the resistances by the resistance inherent in a thermionic valve. This resistance, and consequently the oscillation frequency, could be controlled or modulated by applying the modulating signal to one of the grids of the "resistance" valve. The problem is under investigation in this Department. It is hoped to reach a frequency deviation far greater than is possible with reactance valve methods.

Acknowledgement.

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CONTENTS.

THE FLOW OF SUSPENSIONS — THIXOTROPY AND DILATANCY

By

JOHN PRYCE-JONES.

The study of the factors involved in the rate of flow of suspensions presents a difficult problem; a problem which is of fundamental interest to the theoretical rheologist as well as to the industrial chemist and engineer. It is important to realise that the study of the flow of suspensions is still in its elementary stages and this lecture should be regarded more as a review of a problem rather than as a survey of established knowledge. Although we can make some definite affirmations regarding the flow of suspensions we must regard them as qualitative in nature and quantitative data must await further developments in theoretical rheology. These statements may be regarded as heretical—but has any rheologist ever succeeded in obtaining consistent results for the viscosity, for example, of a paint or a toothpaste or a mayonnaise when observations have been made in a capillary tube, a Couette, a Searle and a falling sphere viscometer? It is very improbable that any rheologist of repute would claim that he has obtained satisfactory agreement; it is even more improbable that four independent observers, each using one of these types of viscometers, would obtain concordant results. Such co-operative experiments deserve a trial, they would reveal the numerous lacunæ in our knowledge of the elements of rheology.

Before we proceed to analyse the various factors which are involved in the flow of suspensions of fine particles in a fluid it is interesting to illustrate some of the problems which confront us immediately we observe the behaviour of the simplest types of dispersions: assemblies of fine particles in true liquids such as water, dilute salt solutions and oils of low viscosity.

For the simplest system we have selected two commercial samples of titanium dioxide each of approximately 99% purity. Suspensions of these qualities are prepared by adding 100 grammes of each to equal parts of water contained in two beakers and the resulting systems are vigorously stirred with a glass rod. It is evident that one system is a free flowing suspension which would flow readily through a capillary tube of one millimetre bore; the other is a stiff paste which will barely flow when the beaker is inverted. The colloid chemist immediately recognises the former as a dispersed system and the latter as a precipitated system—in one the particles are

de-flocculated and in the other they are flocculated. A complete understanding of these two states is the most fundamental step in colloid chemistry and its significance in the study of rheology is obvious.

The next experiment illustrates the effect obtained when two different liquids of the same viscosity are mixed with equal weights of the same solid particles. 100 grammes of TiO_2 are mixed with an equal weight of non-polar paraffin of 3.8 poises viscosity and the system stirred with a glass rod; 100 grammes of the same TiO_2 are now stirred with an equal weight of an oil of 3.8 poises prepared by blending 4 parts of linseed oil with 1 part of polymerised linseed oil. Equal volumes of these systems are placed side by side on an inclined glass plane—the former system remains in its original position but the latter flows readily down the inclined plane; the former is a plastic but the latter is a free-flowing fluid.

The third experiment illustrates the effect of traces of electrolytes upon the flow of suspensions; 100 grammes of a siliceous earth are mixed with an equal weight of water and one obtains a rigid paste which will not flow when the beaker is inverted. On the addition of 25 milligrammes of sodium silicate in 5 mls. of water the system is converted into a free flowing dispersion but on the further addition of 10 milligrammes of magnesium chloride in 5 mls. of water one again obtains a stiff paste which is entirely devoid of flow.

These three simple experiments demonstate that the rate of flow of a suspension is not determined by the ratio of the weight or volume of the suspended particles to the volume of the liquid, but that it is largely determined by the nature of the solid phase, the nature of the liquid phase and by their surface relationships. It is the purpose of this lecture to investigate the various factors which determine the rate of flow and to illustrate some of the experimental methods which have been used to determine these factors.

It is evident that the viscosity of the fluid in which the particles are dispersed must influence the rate of flow of the resulting dispersion; it is therefore necessary to adopt some criterion of the rate of flow which is independent of the viscosity of the dispersing fluid. The accepted criterion is the "relative viscosity" which is defined in the following way:—If an assembly of particles is dispersed in a fluid of viscosity V_f to produce a suspension of viscosity V_s the relative viscosity V_r is the ratio V_s/V_f. The general problem of the flow of suspensions is to find the value V_r in terms of the various factors which influence the rate of flow of an assembly of particles dispersed in a fluid. In our present state of knowledge we do

not know all the factors which may be involved but I have, provisionally, assumed that there are eight distinct factors, so that stated more precisely the general problem is to determine the form of the function:—

$$V_r = F(t, c, r, f, \eta, S, \theta, D.)$$

where t, is the temparature.
c, is the volume concentration of the particles.
r, is the mean particle size.
f, is the anisotropy factor for particle size.
η, is the viscosity of the fluid.
S, is the rate of shear.
θ, is the degree of thixotropy or hysteresis factor.
D, is the co-efficient of dispersion of the fluid.

Time does not permit a complete discussion of these various factors, a brief reference must be made to each of them but I propose to devote most of my remarks to those factors with which my own work has been particularly concerned.

(1) **Temperature.** It has been found that the relative viscosity decreases with increase in temperature and as illustrative examples we select the observations of Mardles [1] for (a) 16.7% by volume of graphite in a mineral lubricating oil; (b) 14.8% by volume of kaolin in meta-cresol and (c) 12.5% by volume of Ultramarine in raw linseed oil:—

(a)			(b)			(c)		
Temp. °C	η_f	η_r	Temp. °C	η_f	η_r	Temp. °C	η_f	η_r
30	3.7	3.6	13.5	1.21	7.7	25	42	3.4
40	1.9	3.4	22	0.15	7.2	60	14.5	2.9
45	1.5	3.1	45	0.05	6.7	95	8.9	2.2

In each case there is an appreciable decrease in the relative viscosity; it should be indicated that Mardles states that the observations were made at " high rates of shear;" it is probable that at low rates of shear the differences in η_r would be much more pronounced.

(2) **The volume concentration of the particles.** In 1906 Einstein [2] deduced a formula for the viscosity, η_s, of a suspension of rigid spheres in any liquid, in terms of the viscosity, η_f, of the liquid and the ratio C of the volume of the solid particles to the total volume.

$$\eta_s = \eta_f \, (1+KC)$$

where K is a constant which Einstein at first considered equal to unity but which he later made equal to 2.5. It is extremely difficult to follow the theoretical reasoning which led to this equation; it is important to realise, however, that it is based entirely on mathematical relationships and that important factors

such as particle size, degree of dispersion and surface relationships are entirely disregarded. A similar formula was deduced by Hatschek (3) for systems where the suspended particles occupy less than 40% of the total volume; it differs from the Einstein formula in using a constant of 4.5. It is not surprising that neither of these formulæ agrees with experimental observations; it is true that at very low concentrations of solids the Einstein equations, in a few systems, is approximately correct; and Harrison (4) found that the Hatschek equation was fairly satisfactory for starch grains in water below a concentration of 30%. It will be evident in the sequel that no formula can be really satisfactory but reference should be made to the important equation of Smoluchowski (5) because it contains a factor involving the effect of electrical charges upon the viscosity of charged particles:—

$$\eta_s = \eta_f \left\{1 + 2{\cdot}5c\left[1 + \frac{1}{\lambda \eta_f r^2}\left(\frac{D Z}{2\pi}\right)\right]\right\}$$

in which λ is the specific conductivity, r the radius of the particle, D the di-electric constant and Z the electrokinetic potential. It is claimed that at very low concentrations this equation is valid for both hydrophilic and hydrophobic sols. In passing it will be of interest to illustrate the very marked differences between the viscosity/concentration curves of two such familiar gums as gum arabic and gum tragacanth; the former gives a curve typical of a hydrophobic sol and the latter of a hydrophilic gel. (Figure 1A). In Figure 1B are shown the viscosity/concentration curves, obtained by the author, for suspensions of TiO_2 in medicinal paraffin and in a polymerised linseed oil of 15 poises viscosity. The former closely resembles the curve for a hydrophilic gel. and the latter for a hydrophobic sol. It will be evident from these two curves that, even at low concentration, a curve of the Einstein type has little practical value. We may therefore infer that increase of volume concentration leads to increase in relative viscosity but that it is highly improbable that a general formula relating concentration and relative viscosity can be obtained.

(3) **Mean particle size.** The classical example of the influence of particle size on viscosity is the work of Oden (6) on sulphur sols., who found that the viscosity increases with the dispersion; for example, sols. consisting of particles 10 $\mu\mu$ in diameter had a viscosity 50% greater than sols. consisting of particles 100 $\mu\mu$ in diameter of the same volume concentration. Hatschek attributed this difference to the difference in absorption of the liquid around the particles; in other words, to the difference in interfacial relationships between liquid and solid and there is no doubt that this is one of the most important

factors in determining the relative viscosity of a dispersion. The author has found similar differences in suspensions of Ultramarine in linseed oil; thus particles of Ultramarine 1 mu in diameter gave viscosities 38% greater than particles of 8 mu in diameter at volume concentrations of 50%. Apparently the influence of the distribution of particle size has not been investigated; for example the difference between particles of uniform

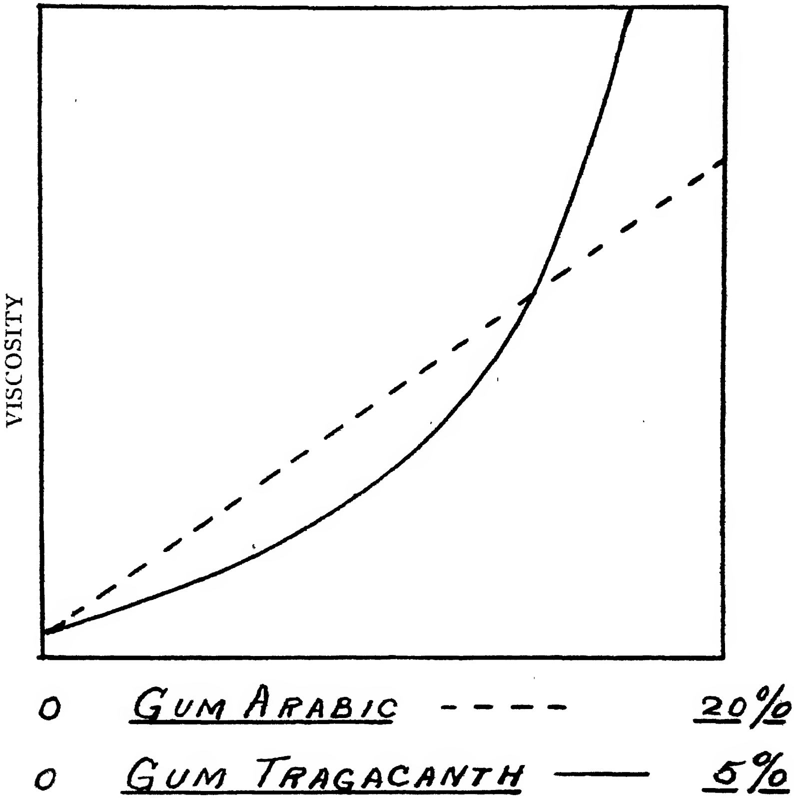

FIG. 1A.

size of, say, 4 mu and a random distribution of particles ranging from 1 to 10 with an average particle size of 4 mu. The problem of particle size is particularly difficult because one cannot guarantee that the interfacial relationships between particle and liquid is a constant factor—the process of subdivision probably changes the surface characteristics of the particle.

(4) **The anisotropy factor for particle size.** In the Einstein equation it is assumed that the suspended particles are rigid

spheres but the majority of industrial suspensions appear to consist of anisotropic particles. It is therefore necessary to introduce a factor embracing the influence of shape—that is laminar, acicular or ellipsoidal particles for example. Various equations have been suggested to compensate for this effect. For example, Kuhn's formula:—

$$\eta_r = \eta_f \, (1 + 2{\cdot}5c + \frac{1}{16} f^2 c$$

where $f = a/b$; a=long axis of an ellipsoid and b the short axis.

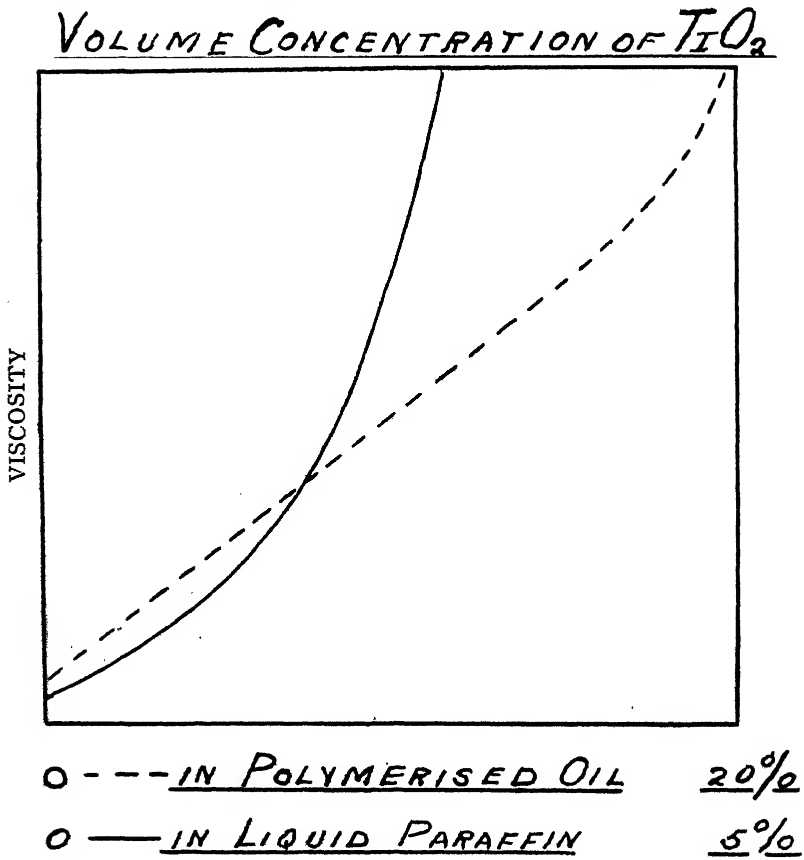

FIG. 1B.

Most of the examples quoted in the literature refer to experiments on different materials which happen to differ in shape but it will be obvious that this is not a rigorous method of approach

as various other factors besides geometrical form are involved. It is essential to deal with the same compound, for example, zinc oxide in spherical and in acicular form respectively. The author recently found that the acicular form of zinc oxide yields suspensions of higher relative viscosity than the spherical form at the same volume concentration in polymerised oils—but even here the results are of little value as the surfaces of each form may have totally different characteristics. Lastly, particle agglomeration may be an important factor as this is equivalent to a change in the degree of asymmetry. In general we can state that the influence of the anisotropy factor has not yet been determined.

(5 **The viscosity of the fluid.** Mardles ([7]) recently investigated the relationship between the relative viscosity of a suspension and the viscosity of the dispersing fluid. From his experimental results he concluded that η_r is a function of η_f " being smaller the lower the values of η_f especially below about 2 centipoises." These results are at variance with the author's observations but as Mardles used very high rates of shear and very low concentrations of solids it is probable that under these conditions the effect of the solid particles was not the predominant factor in determining the viscosity of the suspensions. For example, Mardles prepared 1.0% dispersions of bentonite in liquids varying in viscosity from 0.3 to 4.6 centipoises, and the maximum relative viscosity observed was 1.10. The accuracy of these observations are not questioned but the influence of the solid phase, determined at high rates of shear, was so small that they can hardly be regarded as sufficient evidence on which to base a generalisation.

The author's experiments were conducted with much more viscous liquids and much higher concentrations of solid, for example with liquid paraffin, 3.8 poises and with polymerised linseed oils ranging from 3.0 to 80 poises. Suspensions of TiO_2, of 60% by weight, gave decreasing relative viscosities with polymerised oils of increasing viscosities. In liquid paraffin the relative viscosity was 35 times greater than in polymerised oil of the same viscosity. All these determinations were made at low rates of shear but parallel results were obtained in a further series conducted at high rates of shear. These results indicate that there is no relationship between the relative viscosity of the dispersions and the viscosity of the fluid.

It is necessary, however, to include the factor η_f in the discussion not because it is concerned with the value of η_f in a true liquid but because it is necessary to draw a distinction between dispersions in true liquids of constant η_f for all rates of shear, and for anomalous fluids in which η_f depends on the

rate of shear. It will be realised, in the sequel, that these two types of fluids give rise to two distinct types of dispersions which differ fundamentally in their rheological properties.

(6) **Rate of Shear.** The investigation of the effects of rate of shear upon the viscosity of colloidal solutions is one of the most important aspects of rheology. It is therefore necessary to obtain a clear idea of the meaning of the term rate of shear when applied to the study of viscosities of liquids and colloidal solutions.

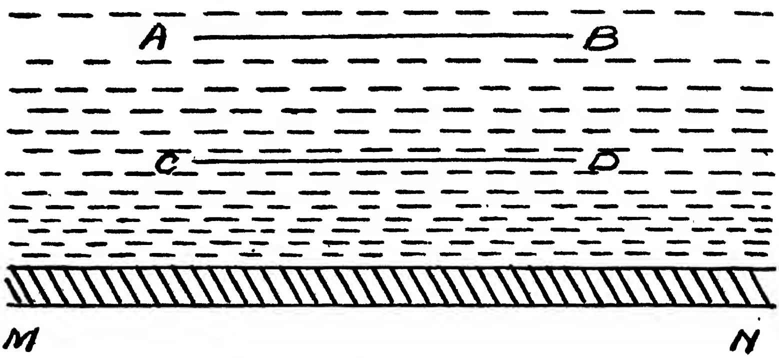

FIG. 2.

If a liquid flows over a horizontal surface represented in Fig. 2 by MN then the layer of liquid next to the surface of the solid is at rest due to the forces of cohesion between the liquid and the solid. The velocity of the liquid in the different layers increases as their distance from the solid increases. Hence the different layers have different velocities, as a result the more slowly moving layer tends to retard the motion of the adjacent faster moving layer, and is itself accelerated by the faster layer. Therefore any layer is acted upon by two tangential forces— above in the direction of motion of the liquid and below by a force in the opposite direction. These two forces are caused by the viscosity of the liquid which may be regarded as a friction between the particles of a liquid when different layers are moving with different velocities.

Consider two layers represented by AB and CD, separated by a distance X, moving with velocities V_1 and V_2 respectively. The velocity gradient between AB and CD is obviously equal to $\frac{V_1 - V_2}{X}$; and in general, if two layers, separated by a distance dx, are moving with a difference in velocity dy then dy/dx is the velocity gradient. It is now the general practice

to refer to the velocity gradient as the rate of shear in a liquid. The rate of shear can be expressed as centimetres per second per centimetre, for example 53 cms. per second per centimetre but as this is equivalent to 53 per second it has become customary to express its value as 53 sec^{-1}. For example if two liquid laminæ separated by a distance of 5 cms. are moving with velocities differing by 130 cms. per second the rate of shear is 26 sec^{-1} but if their distance apart is only 0.1 cm. the rate of shear is 1300 sec^{-1}.

If two laminæ of area of contact *A* separated by a distance *x* are moving with a difference of velocity *y* then the force, *F*, necessary to maintain this constant difference of velocity is

$$F = K \cdot A \cdot \frac{y}{x}.$$

The constant *K* is called the viscosity of the liquid and is usually represented by η. It has been generally assumed that η is constant for a true liquid at constant temperature and that it is independent of the rate of shear. A liquid which conforms to these assumptions is described as a Newtonian liquid. The dimensions of viscosity are

$$ML^{-1}\ T^{-1}$$

and the co-efficient of viscosity may be defined as the force required per unit area to maintain a unit difference of velocity between two parallel planes a unit distance apart. The co-efficient is usually measured in dynes, centimetres and seconds; the value of the unit of viscosity is called a poise (in honour of Poiseuille) and its hundredth part a centipoise. The co-efficient of viscosity for water at 20° C is approximately one centipoise.

In the study of colloidal suspensions at different rates of shear one finds that they can be classified into three groups which are illustrated in Figure 3 in which rates of shear are measured along the abscissae and viscosity along the ordinates. In the first group described as true or Newtonian liquids the viscosity is independent of the rate of shear; the second group are described as anomalous fluids and their viscosity decreases with increasing rate of shear; and in the third group, described as dilatant fluids, the viscosity increases with increasing rates of shear beyond a certain minimum rate of shear.

(For the sake of completeness it is necessary to refer to very recent work on true liquids at very high rates of shear, that is the order of 10^5 or 10^6 sec^{-1} as it is stated that under these conditions even pure liquids become anomalous fluids, that is their viscosity is not constant but decreases with increasing rate of shear. So far only a very limited number of papers dealing with this problem has been published and the results do not in any way influence the subjects discussed in this paper.)

The influence of the rate of shear upon the viscosity of colloidal solutions was first observed by Garrett and du Pre Denning who investigated the viscosity of a number of colloidal systems by means of an oscillating disc method. A disc oscillating in a true liquid obeys the laws of harmonic motion; the ratio of one amplitude to the next amplitude is independent of the amplitude. Garrett and du Pre Denning found that the

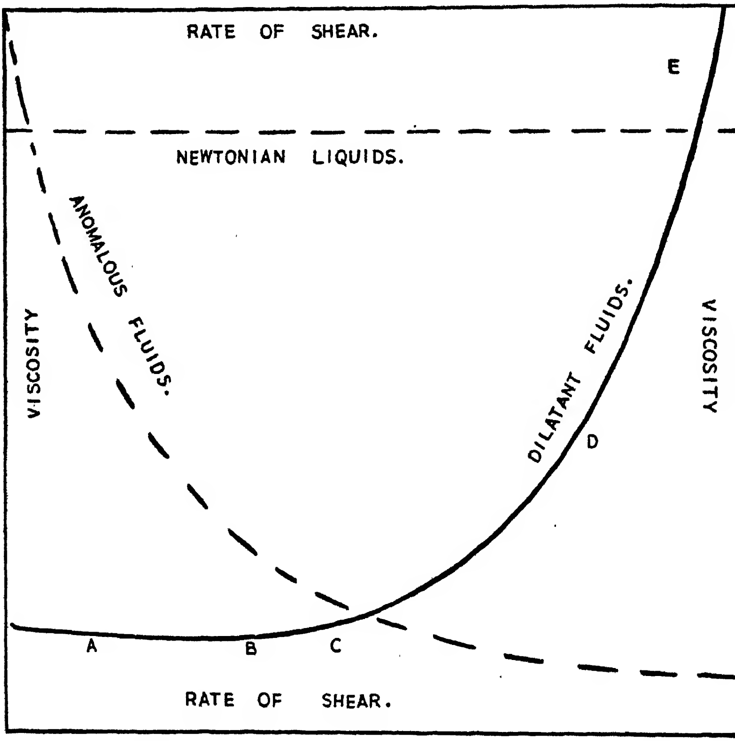

FIG. 3.

viscosities of colloidal solutions depended upon the amplitude of oscillation; it was found that the viscosity increased with decreasing amplitude, that is the viscosity increases with decreasing rate of shear. In 1906 Hess studied blood, serum and many colloidal solutions in a special capillary viscometer in which the volumes discharged at different pressures were measured: with true liquids such as glycerine and water he found that the volumes were proportional to the pressure but with many colloidal solutions the volume was not proportional

to the pressure but increased much more rapidly; for example with a two-fold increase of pressure there was more than a two-fold increase in the ratio of the volumes discharged. In other words, these solutions behaved as if the viscosity decreased with increasing pressure; that is with increasing rate of flow or rate of shear. A few years later Hatschek [8] and his associates found by means of the Couette concentric cylinder viscometer, that certain suspensions of solid particles in liquids showed the same characteristics. It is now recognised that the viscosity of a large proportion of colloidal solutions and of suspensions is not constant but depends on the rate of shear and the study of the rheological properties of colloidal systems plays a predominant part in modern colloidal chemistry.

The concept of a variable viscosity appears to present considerable difficulty to a great many students of colloid chemistry and it is therefore necessary to demonstate the reality of this phenomenon by simple experimental methods with the minimum of mathematical argument. Some years ago the author designed a modification of the Couette viscometer in which the colloidal system can be sheared at three different rates of shear. This apparatus gives "pointer readings" for a true liquid which are independent of the rate of shear but the pointer readings are dependent on the rate of shear for systems which possess variable viscosities. [9]

The apparatus is represented in elevation in Fig. 4 in which *AAAA* is the rotating cylinder mounted on a recessed table driven by an upright spindle carried in the circular framework *CCCC*, which forms the base of the instrument, and is supported on three levelling screws. The upright spindle is driven by the skew-gearing, *S*, connected to the gear-box, *G*, which in turn is driven by the pulley, *P*, connected to a constant-speed motor through a 100 to 1 reduction gear. The pulley rotates at the rate of 14 revolutions per minute and by the appropriate selection of gears the cylinder can be made to rotate at either 4, 14 or 49 revolutions per minute. These speeds are in the ratio of 2:7:24.5. The upright circular pillar, constructed from three brass tubes, carries the torsion wire, TT^1 from which the inner cylinder, *B*, is suspended from a slender brass rod terminating in a small chuck. This rod carries the graduated circular disc, *D*, and adjacent to it is the pointer, *P'*, mounted on the base of the instrument. The upright pillar is capable of rotation within the limits prescribed between two tubes, so that the zero of the scale can be brought in line with the pointer. It is evident that the description, so far, corresponds with that of the simple form of a Couette viscometer and the instrument could be used as such for the determination of the absolute viscosities of liquids.

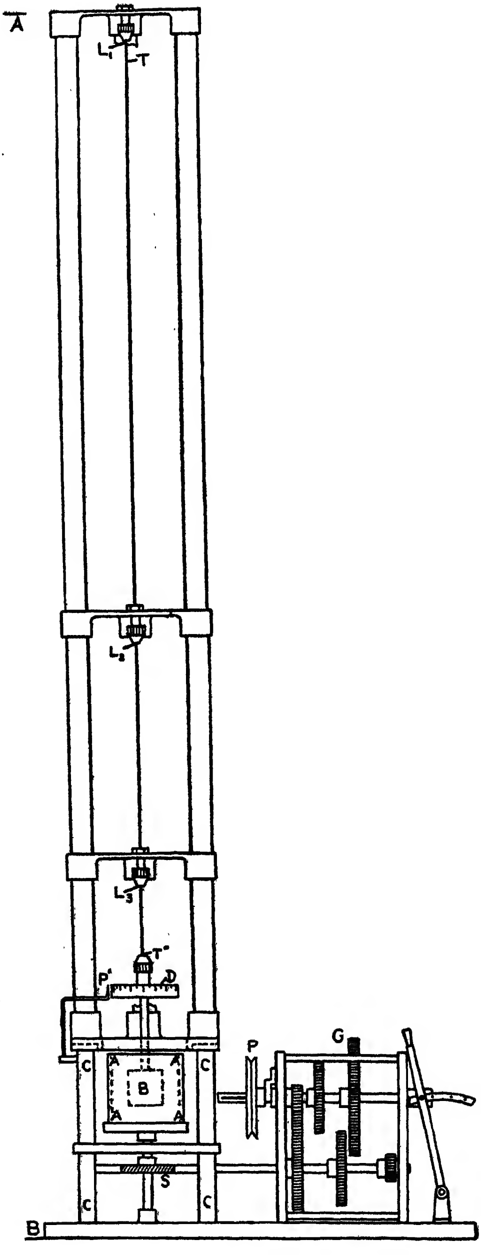

FIG. 4.

The chuck, L_1, is carried on a " spider " at the top of the pillar, in addition two other " spiders " carrying the chucks, L_2 and L_3, are mounted on the pillar. The lengths L_1T', L_2T' L^3T' are 24.5 inches, 7.0 inches and 2.0 inches, respectively. The effective length of the torsion wire can be made to assume one of these three lengths by using the appropriate chuck. Thus, if a length of 24.5 inches is required the chuck L_1 is closed and the wire passes freely through the other two. It will be seen that the effective lengths of wire are in the same ratios at the three rates of revolution of the rotating cylinder. The observations are made by using the following combinations of speeds and effective lengths of wire:—

Length of wire	Revs. per minute	Numerical product
24.5	4	98
7.0	14	98
2.0	49	98

In other words, the numerical product is always a constant, or the length of wire is inversely proportional to the speed of the rotating cylinder. It should be emphasised that these combinations are the only combinations permissible for obtaining true " pointer readings " with this apparatus. (Any gear ratios could be selected at random, but these were chosen as no other gear wheels were available at the time. For other gear ratios a corresponding change is necessary in the lengths of wire.)

The method of using the apparatus is, briefly, as follows:— The upright pillar is removed from its base and placed on a cradle which supports it in a vertical position so that the cylinder, *B*, when suspended, hangs freely in the air. The torsion wire is threaded through the three chucks and fixed to the chuck carrying the scale and inner cylinder. The end of the wire projects beyond the chuck L_1 and is drawn upwards until it feels taut when a 2-inch gauge is held between L_3 and T'. The chuck L_1 is then closed. The fluid under test is then stirred and poured into the rotating cylinder which is then placed on the recessed table and the upright pillar is placed in position on the base so that the suspended cylinder is immersed in the fluid. The pillar is rotated so that the zero on the scale is in line with the pointer. The gear ratio is set so that the cylinder will rotate at 4 revolutions per minute. The fluid in the cylinder is stirred by using the suspended cylinder as a stirrer; the motor is then set in motion. As soon as the outer cylinder begins to rotate the suspended cylinder follows, and after an interval of time it comes to rest and the reading on the scale is observed. (All readings are *equilibrium* readings in Table I.) The motor is stopped; the gear is changed to 14 revolutions per minute and the chuck L_2 is closed. The fluid is again stirred, the motor is set in motion and the scale reading observed when the suspended

cylinder has come to rest. A third observation is made when the outer cylinder is rotated at 49 revolutions per minute and the chuck L_3 has been closed.

These three observations are sufficient to determine whether we are dealing with a true liquid, an anomalous fluid or a dilatant fluid. The observations on thixotropic fluids will be dealt with later.

The scale graduation can be chosen at will, but it has been found convenient to use a true liquid of 50 poises as a standard and designate this deflection as 50. A scale was therefore constructed by observing the deflection produced by an oil of 50 poises viscosity and dividing the observed deflection into 50 equal parts so that one scale division corresponds to a viscosity of 1 poise. It was found that each scale division was equal to 2.66 degrees, so that the complete circle corresponds to 135 scale divisions (that is 360/2.66).

The diameter of the suspended cylinder is 1.5 inches and that of the rotating cylinder is 2 inches, so that the effective rates of shear at the three different rates of shear, as calculated from the usual formula, are:—

Revolutions per minute	Rate of Shear σ (sec^{-1})
49	17.80
14	5.09
4	1.45

(The experiments were conducted at a temperature of 18° C.)

The following table shows some of the results obtained:—

Table 1

	Revolutions per minute 49	14	4
		Deflections	
I			
Standard Oil	50	50	50
Medium Stand Oil	82	82	82
Castor Oil	9.8	9.8	9.8
Dehydrated Castor Oil	108.5	108.5	108.5
Lithographic Varnish	94.6	94.6	94.6
Clover Honey	142.4	142.4	142.4
A White Enamel	14.6	14.6	14.6
II			
1.3% Gum Tragacanth "A" ...	1.6	2.8	4.0
1.3% Gum Tragacanth "B" ...	1.2	2.1	2.7
1.0% Gum Karaya	9.0	17.6	40.6
5.0% Bentonite	0.8	2.1	5.7
5.0% Bentonite	3.4	7.4	14.8
Hair Cream	21.4	36.7	54.6
Mayonnaise	28.5	43.8	68.6
Cod-Liver Oil Emulsion	25.6	27.4	33.8
Adhesive Paste	65.7	84.5	118.8
Furniture Cream	48.4	79.3	174.8
A White Gloss Paint	14.6	16.3	20.4
A Green Enamel	8.4	12.8	21.8
White "Undercoat Paint" ...	12.2	32.6	62.8

	Revolutions per minute		
	49	14	4
		Deflections	
III			
A Bitumen Emulsion Paint ...	46.8	38.4	38.4
A Vinyl Resin solution	84.7	26.7	26.7
Calcium Naphthenate Solution 6.5%	>800.0	134.8	96.6

Note—Table I shows the three different types of systems which can be distinguished by variation in the rate of shear. In this table the influence of time is not considered.

These examples show clearly that three different types of fluids can be distinguished by direct observation of the " pointer readings." In the first group the " pointer readings " are independent of the rates of shear; that is, the fluids are true Newtonian liquids so that their true viscosities are equal to the scale readings based on the standard liquid of 50 poises. (It should be indicated that these results do not show that the viscosities are independent of time.) The next group show " pointer readings " which depend on the rate of shear, and in each case the lowest reading corresponds to the highest rate of shear; that is to say, the members of this group possess anomalous viscosities. As they do not obey the laws of flow of Newtonian liquids their " viscosities " cannot be determined. Nevertheless, valuable qualitative observations can be made from the value of the deflections thus obtained; for example, it is obvious that the two samples of gum tragacanth possess very different properties and that the first sample is very much superior to the second. Similarly, it may be inferred that far better gels could be produced from the second sample of bentonite than from the first. It is also fairly obvious that the white " undercoat paint " possesses a high degree of structure which is readily broken down under shear. The systems in the last group show increasing " viscosities " with increasing rates of shear so that they represent dilatant fluids. In the first two members of this group no increase in viscosity is observed at the medium rate of shear, which shows that the viscosity increases above a certain minimum rate of shear only. The phenomenon is very marked in the calcium napthenate solution, which shows an appreciable increase in viscosity at the medium rate of shear, and at the highest rate of shear the " viscosity " is sufficient to cause permanent distortion in the wire if the rotating cylinder is kept in motion for 15 seconds or more.

Space does not permit a description of the author's " twin-Couette " apparatus but a detailed account has been given in an earlier paper.[10] It consists, in principle, of two identical Couette units rotating in opposite directions and their respective speeds can be set at any selected constant ratio; the inner cylinders are mounted on the same spindle suspended from a

single torsion wire. The viscous force in each unit can be balanced by adjusting their angular velocities so that they are inversely proportional to the viscosities of the liquids in the rotating cylinders. The ratio of the two angular velocities is now set at this constant value but their actual velocities are varied. It is evident that if the two liquids are Newtonian the torsion system remains in equilibrium but if one of the cylinders contains an anomalous or a dilatant fluid then a small change in angular velocities deflects the torsion system from its position of equilibrium. In this way it is possible to observe changes in viscosity induced by a rate of shear differing by 0.1 sec^{-1} and to observe shear hardening in dilatant fluids at constant rates of shear. The apparatus can readily be adopted also to the measurement of very low yield values, and to the study of very slight differences in the viscosity of thixotropic systems.

(7) **Thixotropy, or hysteresis factor.** It has been recognised for a long time that colloidal systems when left at rest may increase in viscosity; in 1927 Freundlich and Peterfi introduced the term thixotropy which they defined as "the isothermal reversible gel/sol/gel transformation induced by shaking and subsequent rest." For example, a suspension of 5% bentonite in water flows freely from an inverted test-tube immediately after shaking but if the suspension is left at rest for a short time it sets into a gel and does not flow when the tube is inverted. On shaking the system becomes fluid and sets anew on being left at rest; the sequence of processes can be repeated indefinitely. The rate of setting to the stage where the gel refuses to flow depends on the diameter of the tube—the time of setting increases rapidly with increase in diameter.

This effect is based purely on hydrostatic principles; if one assumes that the gel is composed of miscellæ or fibrils which are resolved into seperate particles during shaking then it is readily seen that the wider the tube the greater the strength of the individual fibrils necessary to support the structure and, therefore, the longer the time necessary for the strength of the fibrils to develop—one may offer a simple analogy with the construction of a bridge, the longer the span of the girder the greater the strength of the girder required to support the bridge.

Closely associated with thixotropy is the phenomenon of rheopexy—which may be defined as the accelerated setting of a thixotropy gel by gentle rhythmic shearing. For example, a vanadium pentoxide sol prepared by the author sets into a rigid gel in a test tube in 12 minutes. If the tube is rolled, in a vertical position, backwards and forwards between the palms of the hands the gel sets in four minutes—the gentle shearing has accelerated the thixotropic setting.

Thixotropy is usually associated with anisometric particles and some writers claim that anisotropy is a necessary condition of thixotropy. It is true that anisotropy is a characteristic of a great many thixotropic gels, for example vanadium pentoxide and bentonite, but it is possible to prepare thixotropic systems from perfectly isotropic particles. The author prepared a 10% dispersion of sulphonated carnauba wax in water which is highly thixotropic. Professor Hauser showed by means of the ultramicroscope, that all the particles are perfectly spherical. It is of interest to add that this system is also rheopectic. So far this is the only thixotropic system composed of spherical particles which has been described in the literature.

In the early development of the study of thixotropy it was assumed that the phenomenon was a peculiar property of certain materials when reduced to a fine state of subdivision. A more accurate conception of the nature of thixotropy can be obtained if we cease to regard a compound as " thixotropic " or " non-thixotropic " but adopt the idea that the " thixotropic state " can be assumed by a large number of compounds under suitably chosen conditions. This concept may be illustrated from a study of the behaviour of bentonite, at a concentration of 5% in water to which traces of various electrolytes are added in the sequence shown in the following table:—

(1) Dialysed bentonite	Peptisation	Hard Settlement
(2) 0.2% $CaCl_2$	Thixotropy	Permanent gel
(3) 0.5% $CaCl_2$	Precipitation	Soft Settlement
(4) 0.5% Sodium Silicate	Thixotropy	Permanent gel
(5) 1.0% Sodium Silicate	Peptisation	Hard Settlement
(6) 5.0% Sodium Silicate	Precipitation	Soft Settlement

Similarly one can obtain a series of different colloidal states by dispersing titanium dioxide in refined linseed oil by addition of various reagents in the following sequence—but maintaining a constant solid/liquid ratio by the requisite addition of TiO_2.

(1) Refined Linseed Oil	Highly Thixotropic	Soft Settlement
(2) 5% Stand Oil	Slightly Thixotropic	Soft Settlement
(3) 1.2% Fatty Acid	Peptisation	Hard Settlement
(4) 2.0% Fatty Acid	Slightly Thixotropic	Soft Settlement
(5) 1.0% Fatty Acid	Highly Thixotropic	Soft Settlement
(6) 10.0% Stand Oil	Peptisation	Hard Settlement
(7) 5.0% White Spirit	Slightly Thixotropic	Soft Settlement

The properties of the suspension, indicated in the second column, show that the presence of thixotropy is conditioned by the composition of the dispersing medium and that the thixotropic state can be induced at will by very small changes in the concentration of the electrolyte in the bentonite dispersion; and by changes of the fatty acid content, the addition of stand oil or white spirit in the linseed oil medium. The third column shows the state of the dispersion after it has been left at rest

for several hours in the case of the bentonite system, and for several months in the case of the titanium dioxide system. The true nature of thixotropy may therefore be summarised in the following quotation:—[11]

"Thixotropy is a phenomenon that should be associated with the colloidal environment rather than with the intrinsic properties of the dispersed particles; it represents one of the manifold of states that a colloidal system can assume in passing from a state of complete peptisation to a state of complete precipitation. If no limitations are placed on the solid phase or upon the nature of the dispersing medium it is possible to select the conditions under which a very large number of systems can be made to assume the thixotropic state."

It will therefore be evident that thixotropy can be induced in a precipitated system by the controlled addition of a dispersing agent; and in a peptised system by the controlled addition of a precipitating agent. Naturally the concentration of the solid phase must be selected within the necessary limits; increase of solid concentration favours thixotropy and decrease of concentration reduces thixotropy.

The two previous paragraphs summarise the fundamental principles involved in the preparation of thixotropic systems and in their conversion into peptised or precipitated systems. The application of these principles to practical problems depends upon the selection of the suitable peptising or precipitating reagent and no general rules are applicable in the making of such a selection. Peptising and precipitating agents are, to a great extent, "specific" in their effects so that only a wide experience of colloid chemistry can assist in their selection in our present state of knowledge.

The quantitive measurement of thixotropy presents the rheologist with a very difficult problem and, so far, no satisfactory method has been evolved. The fundamental difficulty is a theoretical one; experimental methods of approach are almost legion but none of these is based on a satisfactory theoretical basis. Although the definition of thixotropy, proposed by Freundlich and Peterfi, is clear and precise, unfortunately they did not give a definition of a sol or of a gel. For rheological purposes we may consider a sol as a colloidal system which possesses no "Yield Value" but a gel is a colloidal system which possesses a measurable yield value—in other words a colloidal sol flows under the influence of a shearing force however small but a gel does not flow until the shearing force reaches a minimum critical value. The dimensions of a yield value are dynes per centimetre square. If therefore thixotropy is an "isothermal reversible gel/sol/gel transformation" it is

evident that the viscosity of a sol and the "viscosity" of a gel are incommensurable, because in the former state we measure a viscosity and in the latter a "Yield Value." Further it is evident that as a sol is a Newtonian liquid its viscosity is independent of the rate of shear but a gel is an anomalous fluid and its viscosity is therefore a function of the rate of shear.

In spite of this fundamental difficulty involved in the measurement of thixotropy it is possible to obtain valuable information regarding the rate of gelation of a thixotropic system—provided that we recognise the limitations of our methods and do not attempt to express our results in absolute measurements. The results of our empirical observations provide us with valuable experimental facts capable of interpretation, and capable of direct application in the most varied scientific and industrial fields.

The Couette viscometer, already described, has shown that there are at least three types of fluid systems—the Newtonian liquid, the anomalous fluid and the dilatant fluid. These three types can be observed without reference to the effect of time upon the "pointer-readings" of the instrument: if now we consider the influence of time upon the viscosity of colloidal suspensons we find that two more distinct types of behaviour are revealed by the "pointer-readings."

In using the Couette apparatus for observing the effects of time upon the "pointer-readings" it is necessary that the systems be left at rest in the apparatus after shearing has ceased. It has been found sufficient to make observations on the effect of time on viscosity at the lowest rate of shear only. As before, the deflection at the lowest rate of shear is observed as soon as stirring has ceased. The experiment is repeated after the fluid has been left at rest for 1 minute and the maximum deflection is observed; similarly the maximum deflection is observed after the fluid has been left at rest for periods of 5 minutes and 25 minutes, respectively. (These times, of course, are purely arbitrary, but they are the same as those selected in my previous papers and which were found to be satisfactory.) As already stated, the viscosity of a thixotropic system increases as the sol changes into a gel. As a gel possesses a Yield Value the suspended cylinder is rotated by the rigid gel until the opposing force created in the deflected torsion wire becomes equal to the Yield Value. At this stage the gel begins to break down under the influence of the applied shearing force so that the suspended cylinder begins to return towards zero, and comes to rest at a value corresponding to the equilibrium value of the viscosity under the applied rate of shear. In other words, it comes to rest at exactly the same deflection as that observed

when the apparatus is set in motion immediately after stirring has ceased. The difference between the maximum deflection and the equilibrium deflection is thus a measure of the increase in viscosity in a thixotropic system after a definite period of time.

Table 2 illustrates the effect of time upon the value of the deflections observed. The first column shows the deflection observed immediately after stirring and is described as " 0 Mins." The remaining columns show the maximum deflections after resting periods of 1 minute, 5 minutes and 25 minutes respectively.

It will be observed that the results are divided into five classes.—

Class A.—These are true liquids, their viscosities are independent of the rate of shear as well as of time of rest after stirring has ceased. They may be taken as absolute values of viscosity based on the viscosity of a true liquid of 50 poises of viscosity.

Class B.—The viscosity of these systems is a function of the rate of shear, and decreases with increasing rate of shear, but is independent of time. In other words, they show anomalous viscosity, which is a function of the rate of shear and the rate of shear only. This I regard as the true criterion of anomalous viscosity. The values of the deflections are true pointer readings, and in my opinion are all that can be claimed for them. It is true that, compared with the standard value for the true liquid of 50 poises, they may be regarded as a figure for apparent viscosity, provided we realise that they are merely pointer readings and nothing more.

TABLE 2

	Maximum readings 4 Revolutions per minute.			
	0 min.	1 min.	5 min.	25 min.
	Deflections.			
Class A:				
Standard Oil	50	50	50	50
Stand Oil	84.5	84.5	84.5	84.5
White Enamel	14.6	14.6	14.6	14.6
Blue Enamel	11.6	11.6	11.6	11.6
Hard Gloss Paint	16.4	16.4	16.4	16.4
Class B:				
40% Gum Arabic	2.9	2.9	2.9	2.9
1.3% Gum Tragacanth 'B' ...	2.7	2.7	2.7	2.7
1.0% Gum Karaya	40.6	40.6	40.6	40.6

Class C:				
Pale Blue Enamel	9.2	9.2	9.6	12.6
Blue Gloss Paint	8.8	9.4	12.8	16.8
White Japan "P"	14.3	14.4	15.6	18.9
Varnish Paint "K"	17.3	17.9	20.2	27.4
Class D:				
90% Heather Honey	26.0	32.2	36.4	43.7
5% Bentonite "P"	14.8	20.6	24.2	28.6
Mid-green Paint	39.4	61.4	66.2	78.6
Light Oak Paint	32.6	42.7	54.9	63.2
Brown Synthetic Enamel ...	49 6	56.7	61.2	66.7
Class E:				
48/52 Maize Starch/Water ...	14.6	14.6	14.6	14.6
30% Gum Arabic /1% Borax ...	16.8	16.8	16.8	16.8
Calcium Naphthenate Solution 6.5%	96.6	96.6	96.6	96.6

Class C.—The viscosities of these systems immediately after stirring are practically independent of the rate of shear; in other words, they are almost true Newtonian liquids. When left at rest for increasing periods of time their viscosities increase as indicated by the values of the maximum deflections. As shearing continues the gel gradually breaks down and the deflection decreases to the value observed when the experiment is made immediately after stirring has ceased. In my opinion this represents the definition of ideal thixotropy as originally formulated by Freundlich and Peterfi.

Class D.—This class represents by far the most prevalent type of non-Newtonian fluids. It will be observed that all the members of this class possess anomalous viscosity immediately after stirring has ceased. Further, their viscosities rapidly increase when left at rest for even a short interval of time, but this rate of increase does not continue with increasing intervals of rest. This type corresponds to False-Body, as described in my earlier papers. Whereas Class C appears to be a true gel/sol/gel transformation induced by shear and subsequent rest, i.e. true thixotropy, Class D appears to be a partial dispersion of a gel under the influence of shear and the rapid reformation of the gel on the removal of shear which, in my mind, should not be regarded as true thixotropy. Systems in all stages of transition between Class C and Class D are found to exist, but nevertheless it is essential to regard thixotropy and False-Body as two distinct properties, and elsewhere (10) I have given evidence that they possess different characteristics. Further, I believe Freundlich's original concept of the reversible isothermal

gel/sol/gel transformation to be such a valuable idea that it will play an ever increasing part in the development of colloid science.

Class E.—The members of this Class are dilatant fluids and the viscosity at the lowest rate of shear is independent of time. It should be realised, however, that when the critical rate of shear has been reached, that is the rate of shear at which the viscosity begins to increase, it has been found that continued shearing at a constant rate of shear leads to an increase in viscosity with time. (In certain systems prolonged shearing at constant rate of shear leads to an increase in viscosity, although no increase is apparent immediately a rate of shear of the same value is applied. This phenomenon is not yet fully investigated.)

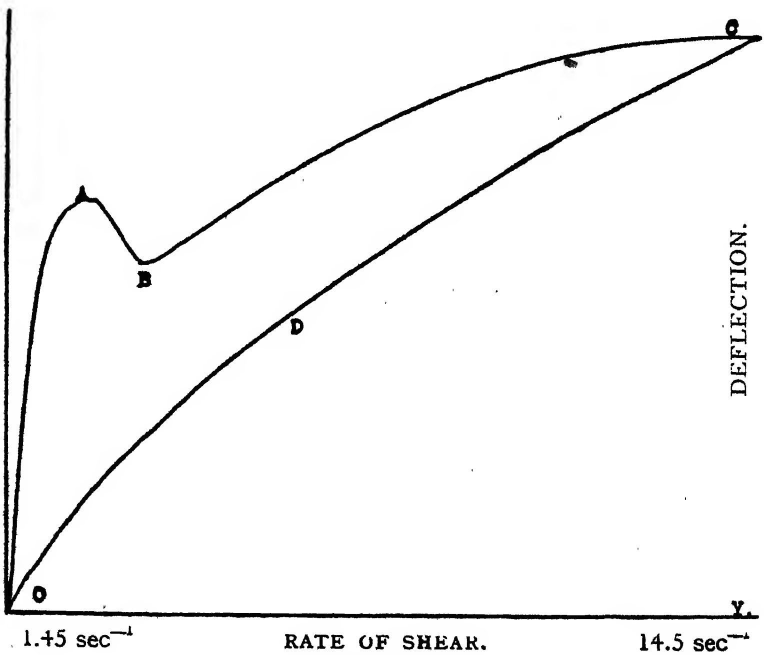

FIG. 5.

We have already used the term "hysteresis" in relation to thixotropic behaviour and a Couette viscometer operated by a continuously variable gear illustrates the hysteresis effect very clearly. If one plots a graph showing the relationship between the angular velocity of the rotating cylinder (that is, the rate

of shear) and the deflection of the inner cylinder one obtains a very clear insight into the nature of thexotropic gelation. For example the curve OABC in Fig. 5 shows the curve obtained from a 5% bentonite gel left to rest in the annular space of the instument for a period of ten minutes. At the end of ten minutes the viscometer is set in motion at the minimum rate of shear and the rate of shear is gradually increased from 1.45 sec^{-1} to 14.5 sec^{-1} during the interval of 5 minutes. The point A represents the maximum deflection and corresponds to the magnitude of the " Yield Value " and continued shearing breaks down the gel to the value represented by the point B. As the rate of shear increases the deflection increases and the curve BC represents the relation between rate of shear and deflection for an anomalous fluid. Where the apparatus is rotating at its maximum angular velocity, represented by the point Y, the velocity is gradually decreased and a curve CDO is thus obtained. The deflections observed during the period of decreasing rate of shear are lower than those obtained during the period of increasing rate of shear at the same values of the rate of shear; and the area between the two curves is a measure of the degree of thixotropic breakdown. In an anomalous fluid, that is a non-Newtonian fluid free from thixotropy, the ascending and descending curves are collinear. The author first demonstrated the significance of hysteresis curves in thixotropic measurements in 1936 and during recent years Green has developed these ideas in a comprehensive study of the rate of " thixotropic " breakdown. ([12])

It has already been shown that the steady deflection of the inner cylinder, when the rotating cylinder is rotating with constant angular velocity, is a measure of the viscosity of the gel at that rate of shear—an equilibrium viscosity determined by rate of shear alone and independent of time. Hence it is important to realise that if hysteresis curves are traced so that the gel is in equilibrium at each rate of shear then the descending and ascending portions of the curve are colinear. This important point is usually overlooked but it is a fundamental feature of thixotropic systems.

The Couette viscometer operating at three different rates of shear illustrates most of the important features of all types of anomalous fluids and the results are capable of wide application. The observations, however, are not always as convincing as we would wish and for more accurate observations of changes in thixotropic systems the author prefers the electro-magnetic thixotrometer which he evolved in 1934. As full details of this apparatus have already been described it will be sufficient here merely to describe the principles involved and some of the results obtained.([13])

A torsion wire, suspended from a torsion head, carries a brass stalk terminating in a nickel plated cylinder immersed in a glass vessel containing the liquid under observation. The brass stalk carries a small circular mirror and an astatic pair of magnetic needles in a horizontal plane. The upper needle lies between two circular coils in series so that the passage of a small

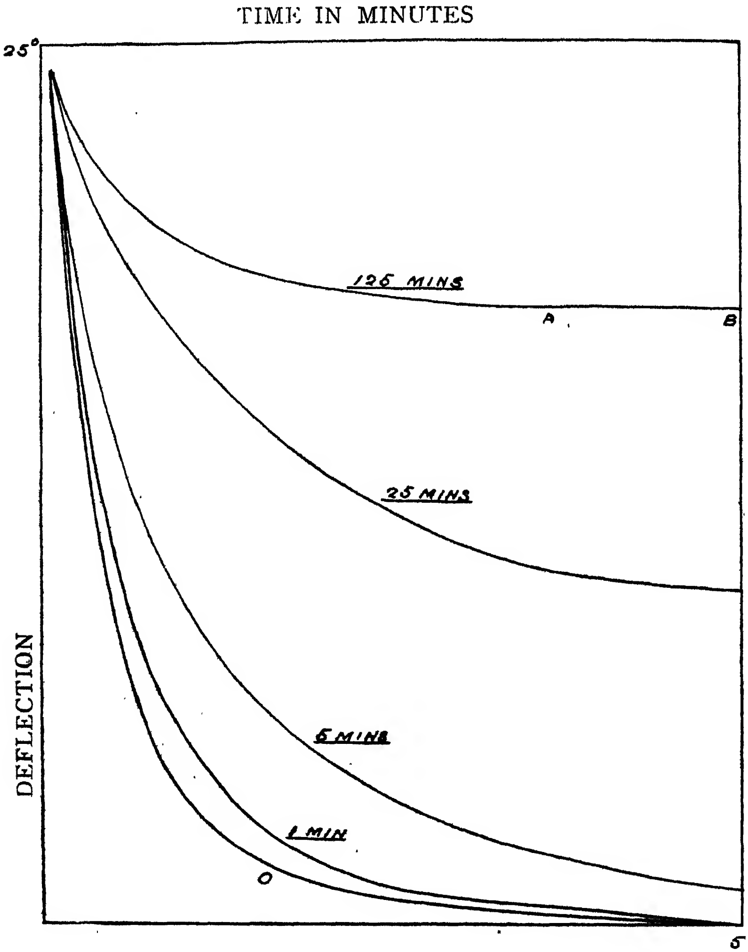

FIG. 6.

A typically thixotropic system. The curve for zero time is exponential indicating that the system is a sol. The remaining curves are not exponential and the portion AB of the 125 minutes curve is parallel to the base. This shows the presence of a Yield Value, the system has become a gel. The system is truly reversible.

current, of the order of one milli-ampere deflects the suspended system through 25° as indicated by the mirror which forms part of the convential optical system. It is evident that such an arrangement affords a simple and delicate method of observing the rotation of the cylinder immersed in the fluid. The method

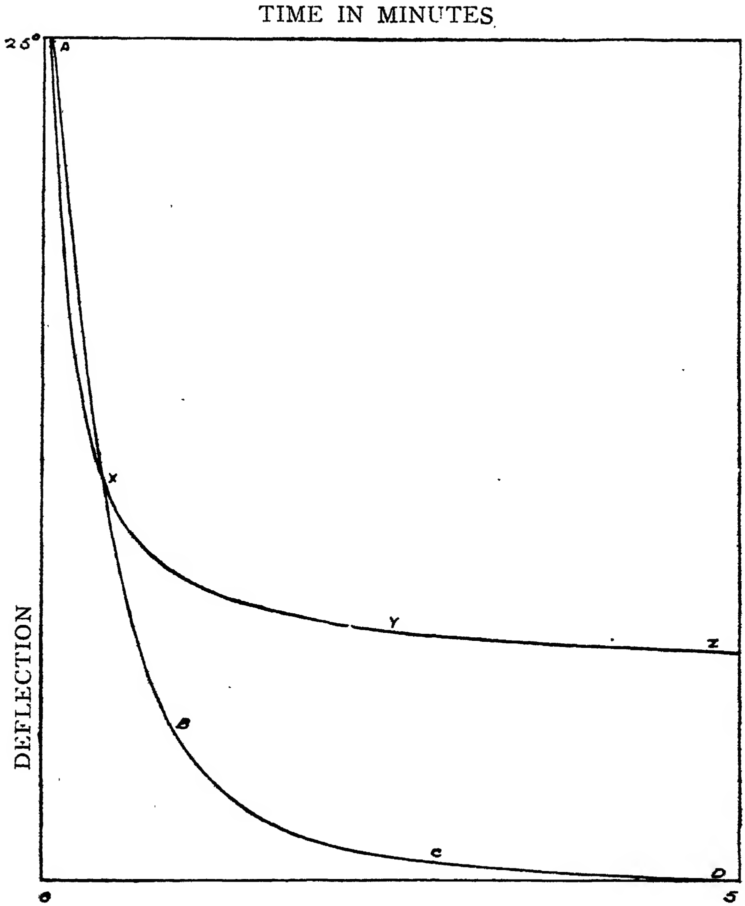

FIG. 7.

The curves show the difference between a Newtonian liquid and an anomalous fluid. The curve ABCD, for castor oil, is a true exponential curve hence it is a true liquid. The curve AXYZ, for a colloidal solution of gum karaya in water, is not exponential in form as it cuts the curve ABCD at X. Its viscosity increases with decreasing rate of shear, it is therefore an anomalous fluid. Its viscosity however is independent of time as identical curves are obtained when the solution has been left at rest over long periods.

consists, briefly, in deflecting the cylinder to 25° by closing the electric circuit, stirring the liquid and breaking the circuit immediately stirring has ceased. If one plots a curve showing the relationship between deflection and time one obtains a true exponential curve for Newtonian liquids. The circuit is again closed and the cylinder deflected to 25°, but is left to rest for *one* minute after stirring has ceased, and a curve is again traced; similarly one traces curves for resting periods of *5, 25* and *125* minutes. For true liquids the five curves are identical; for anomalous fluids the five curves are identical but are not true exponential curves; but for thixotropic systems one obtains a series of curves of which the curve immediately after stirring is exponential in form, but the other four are similar to those obtained for anomalous fluids—in other words, the system is a sol immediately after stirring but becomes a gel when left at rest. Further the system now possesses a " Yield Value " because the curve never reaches zero as the torsion in the wire is unable to overcome the rigidity of the gel.

Fig. 6 illustrates the effect obtained with a typical thixotropic fluid; the curves labelled 0, 1, 5, 25 and 125 are those traced after the gel has been left to rest for the indicated period of time.

Fig. 7 illustrates the difference between true liquids and anomalous fluids. The curve ABCD was obtained for castor oil of approximately 10 poises viscosity; and the curve AXYZ for a 2% dispersion of gum Karaya in water. The latter cuts the true exponential curve at the point X, above this point its viscosity is less than 10 poises but below this point its viscosity exceeds 10 poises—in other words, under the influence of a high shearing force, produced by the large deflection of the torsion wire and high rate of shear its viscosity is lower than under the influence of a low shearing force and a low rate of shear. The curve however remains the same irrespective of the time the system has been left at rest.

A study of suspensions by means of this thixotrometer affords a simple means of predicting their behaviour when left to rest for a long period—for example a paint or an abrasive liquid polish or a pharmaceutical dispersion of fine particles. In a study of over 500 paints, over a period of many years, the author found that the curves obtained could be classified into four groups, as shown by the four sets of curves in Figure 8.

The following remarks describe some of the principal differences observed in the four classes of paint after they had been aged over periods of several months:—

CLASS I.

The curve shown represents four coincident curves obtained after resting periods of 0, 1, 5 and 25 minutes. There is no

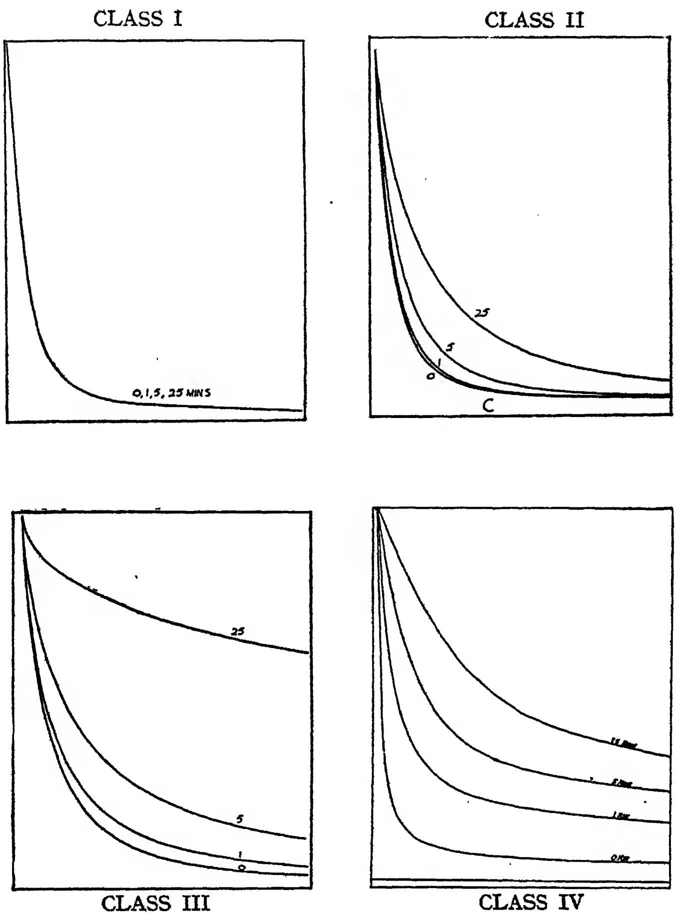

FIG. 8.

Four classes of paints indicated by the thixotrometer curves.

Class 1. Entire absence of thixotropy; this condition leads to hard settlement.

Class 2. Slight thixotropy; these paints form a thin adherent layer below a sticky settlement which can be stirred with difficulty.

Class 3. Marked degree of thixotropy.

Class 4. Marked degree of thixotropy of the "False-Body" type. Paints in classes 3 & 4 usually remain homogeneous but if they develop syneresis they can easily be redispersed by shaking.

indication of the presence of thixotropy, and the form of the curve is identical with that obtained with a true liquid such as glycerine.

This class is chiefly represented by enamels and enamel paints; these contain a low solid concentration and a high proportion of gums or other dispersing agents.

All the members which fall into this class form hard settlements on ageing; the surface of separation between solid and liquid is perfectly defined when sounded with a glass rod. The liquid layer is often coloured with a very low concentration of particles of the pigment in active Brownian movement. The fineness of these particles, their high degree of peptisation and their active Brownian movement, enables them to remain in suspension for a very long time.

In general, the absence of thixotropy implies complete dispersion of the pigment, and, therefore, leads to a hard settlement. As these paints are entirely free from rigidity or any internal structure the particles, which obviously are too coarse to be regarded as truly colloidal, settle under the influence of gravity in the same manner as a disperse system of China Clay forms a hard settlement in water.

Class II.

Slight evidence of thixotropy is observed after five minutes resting period and a distinct changing of viscosity in 25 minutes. On ageing a very thin adherent layer is found at the bottom of the tin and superimposed by a " sticky " or tenacious settlement which can be stirred with difficulty. If a glass rod is stirred into such a settlement and drawn to the surface, a plastic " pear " adheres to the end of the rod. This type of settlement is familiar to every paint chemist. The concentration of pigment rapidly falls with increasing height of liquid, and frequently a clear layer is found in the upper half of the tin.

Class III.

In this series the presence of thixotropy is quite distinct, and a large proportion of paints are found in this class. Generally they remain homogeneous for very long periods of time, and may be almost regarded as stable systems.

There are many exceptions, however, as these systems sometimes resolve themselves into two distinct layers. The upper layer consists of the medium pure and simple and the lower layer of a concentrated paste formed by the deposition of the pigment. The paste is readily made fluid by shaking the tin and a homogeneous system is again obtained.

Class IV.

These curves represent a class of paint which is very abundant. The change in viscosity is very marked in the first minute, and can often be observed in five seconds after stirring has ceased.

The behaviour of the paints in this class is very anomalous on ageing. A great many are permanently stable; a few develop syneresis, and the thick paste obtained is easily stirred.

Although these particular experiments refer to paints, that is dispersions of pigments in oil media, the general principles are applicable to all types of colloidal systems. A completely dispersed system, that is one which is devoid of any anomalous viscosity or thixotropy, when left at rest for a long period yields a hard coherent layer of particles on the base of the container; this layer is much too compact to be re-dispersed by violent shaking or by stirring with a glass rod. Such effects are often observed in suspensions of abrasive polishes, pharmaceutical preparations and numerous other products offered for sale as homogeneous dispersions, their formulation betrays the ignorance of the principles of colloid chemistry. Complete dispersion is therefore not desirable in colloidal preparations expected to remain as homogeneous products for a long period of time. On the other hand, as will be shown later, complete dispersion is essential for the separation of fine particles, from suspension, into different ranges of particle size as they settle, according to Stokes' law, under the influence of gravity during varying periods of time.

The ideal condition for maintaining a homogeneous suspension over long periods of time is the presence of a certain degree of thixotropy. This condition can be attained by the controlled degree of precipitation or peptisation and by selecting the appropriate volume concentration of dispersed particles. If the formulation does not permit the addition of the necessary quantity of solid particles then it is essential to bring the system to the precipitated state so that the particles settle into a soft gelatinous layer which can be readily re-dispersed by shaking the container. In this condition the system will probably be resolved into two layers—a clear supernatant layer overlying a concentrated layer of suspension.

It is true that there are exceptions to these generalisations; preparations of colloidal silver, for example, can be prepared in the completely dispersed state and do not settle for very long periods of time. The conditions arise from the extremely fine state of subdivision of the particles and their very active Brownian movement which overcomes the force of gravity. In ordinary industrial preparations, however, the particles are

usually at least 1 mu in diameter and generally very much larger. In such systems the Brownian movement is not sufficient to keep them in suspension for long periods.

The electro-magnetic thixotrometer can also be used in the study of the elasticity of colloidal systems. If the suspended cylinder is deflected to 25° by means of a current of one milli-ampere or so and the current then reversed and increased to say 30 milli-amperes the cylinder rapidly returns to its zero position.

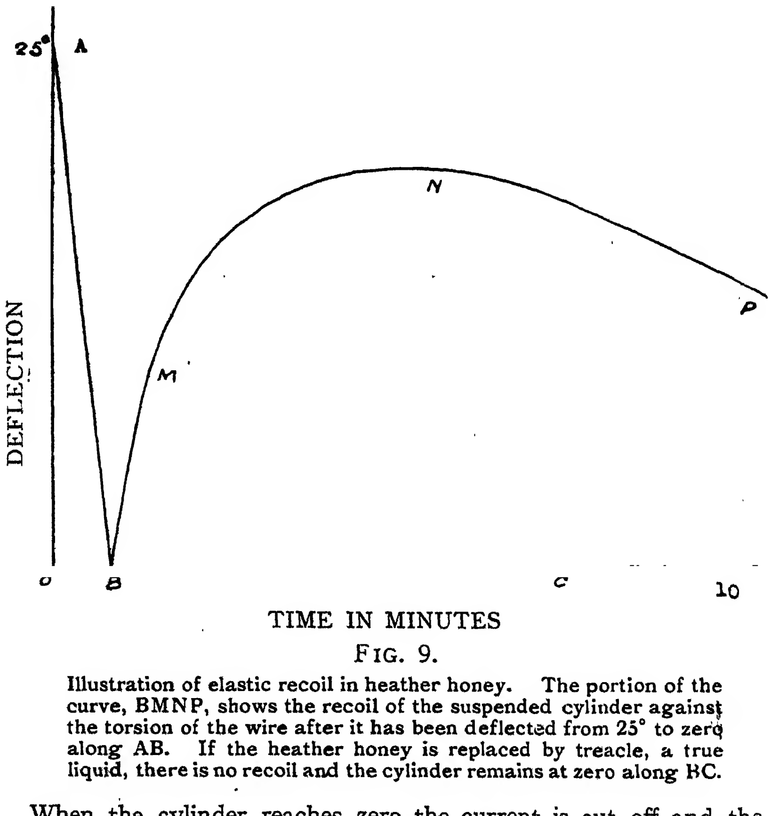

FIG. 9.

Illustration of elastic recoil in heather honey. The portion of the curve, BMNP, shows the recoil of the suspended cylinder against the torsion of the wire after it has been deflected from 25° to zero along AB. If the heather honey is replaced by treacle, a true liquid, there is no recoil and the cylinder remains at zero along BC.

When the cylinder reaches zero the current is cut off and the resulting movement of the cylinder is determined by the properties of the fluid in which it is immersed. For example if the fluid is a Newtonian liquid such as treacle or castor oil the cylinder remains at zero; but if one immerses the cylinder in heather honey, for example, one obtains a violent recoil of the cylinder immediately the current is cut off. These effects are illustrated in Fig. 9. ABC represents the deflections of the

cylinder in treacle; and ABMNP in heather honey. There is a violent recoil due to the elasticity in the honey induced by the rapid shearing effect due to the rotation of the cylinder along AB. Similar effects are observed in any thixotropic or anomalous fluids so that it is evident that the "viscosity" of such systems is determined by at least two factors, true viscosity and elasticity. Any complete mathematical analysis of the nature of viscosity of anomalous fluids should therefore contain a factor dependent upon the elastic component of the apparent viscosity.

We have already indicated that the factor η_f has been included because it is necessary to distinguish between liquids with constant viscosity and anomalous fluids. Anomalous fluids possess the property of elastic recoil whereas true liquids possess no elasticity; for example polymerised linseed oil with a viscosity of 3 poises possesses no elasticity as it is a true liquid but if one dissolves two per cent. of zinc linoleate in the oil the solution is an anomalous fluid and shows elastic recoil; the polymerised oil has a constant viscosity η_f for all rates of shear but the viscosity of the solution of zinc linoleate is a function of the rate of shear. Hence it is natural to expect that dispersions of fine particles in polymerised oil will possess different properties from those in the solution of zinc linoleate in the oil. Experimental evidence shows that this expectation is true as will be shown later.

Reference has already been made to the viscosity of the fluid as a factor influencing the relative viscosities of suspensions. It was indicated that there is no relationship between the numerical value of η_f and η_r but that the rheological character of the dispersion depends upon whether the dispersing fluid is a true liquid or an anomalous fluid.

The influence of the nature of the dispersing fluid is well illustrated by comparing the properties of suspensions of TiO_2 in boiled linseed oil and in boiled linseed oil containing 1.0% of zinc oleate (or zinc linoleate). Boiled oil is a true liquid but on the addition of 1.0% of zinc oleate (or zinc linoleate) it becomes an anomalous fluid and possesses elastic recoil. A dispersion of 40 parts of TiO_2 in 60 parts of boiled oil is entirely free from thixotropy but the dispersion containing zinc oleate rapidly increases in viscosity when left at rest and the curves obtained by means of the electro-magnetic thixometer are shown in Figure 10. It is evident that even immediately after stirring the system is not a sol but a gel as the curve differs greatly from the exponential form. The suspension therefore is of the "False-Body" type. It is interesting to compare the disposition of the curves with those in Figure 6 which was a suspension of 70 parts by weight of the same TiO_2 in 30 parts of

the same boiled oil (but free from zinc oleate). In this system thixotropy has been induced by the effect of the high solid concentration—as compared with the non-thixotropic paint obtained at 40% solid concentration. A comparison of Figure 10 and Figure 6 shows that in the False-Body system there is a very rapid increase during the first minute but the rate of increase

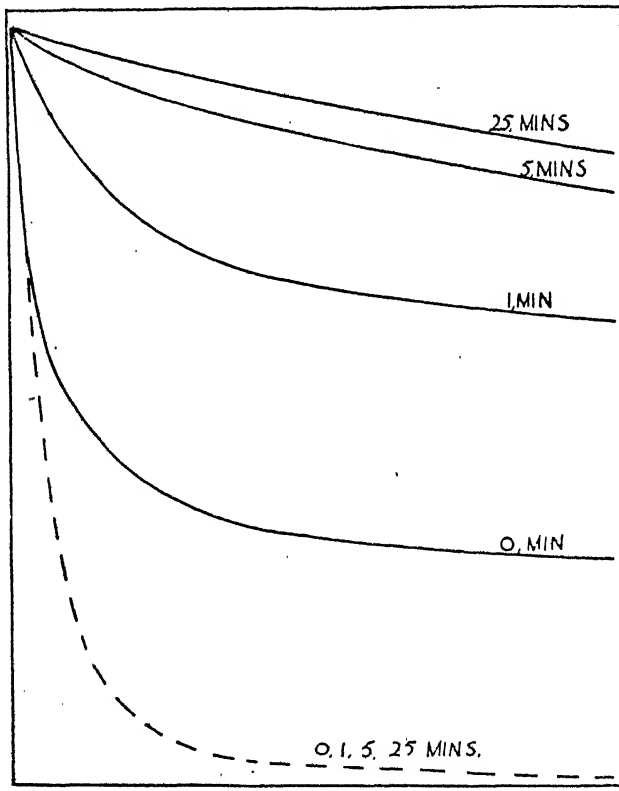

FIG. 10.

A typical set of curves for a " False-Body " system. The zero curve is not exponential in form; there is a very rapid increase in viscosity during the first minute and during the first five minutes. The rate of increase then falls off. The broken line shows a true exponential curve.

in viscosity decreases with longer periods of time; in the thixotropic paint there is a very slow increase during the first few minutes but the rate is accelerated during longer periods—briefly the relationship in a False-Body system is hyperbolic but in a thixotropic system it is sigmoidal. ([10])

Further the False-Body system possesses elastic-recoil immediately after stirring has ceased; the thixotropic system possesses no elastic-recoil immediately after stirring but it is developed in the course of time in conformity with Freundlich's

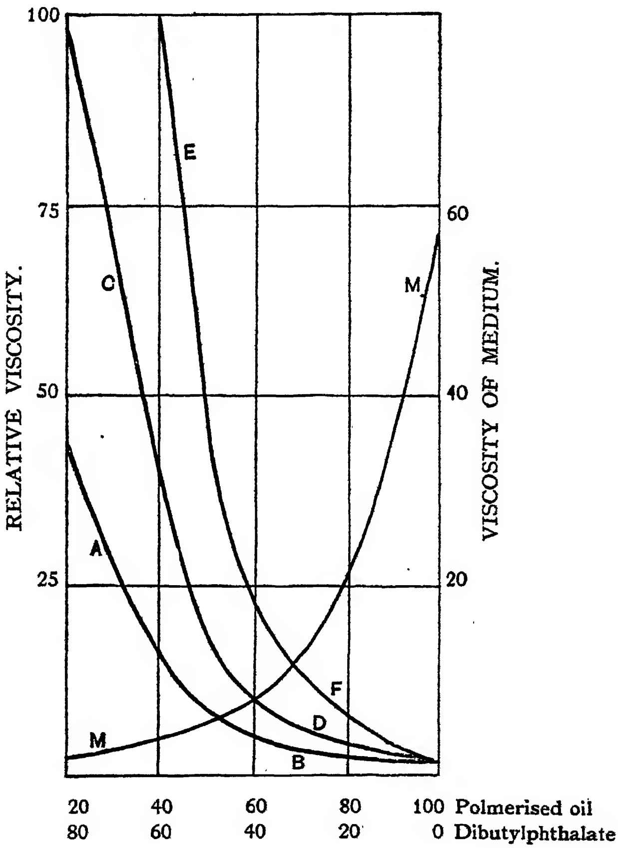

FIG. 11.

Suspension of zinc oxide in a medium with varying proportions of polymerised oil and di-butyl-phthalate. The curve MM is the viscosity of the medium. The other three curves show the value of the relative viscosity at three different rates of shear.

AB for the value 2.7 sec^{-1}; CD for 0.45 sec^{-1} and EF for 0.18 sec^{-1}.

These results were obtained with the twin-Couette viscometer.

original definition. On the other hand False-Body represents the partial dispersion of a gel under the influence of shear and the re-formation of the original gel structure on the removal of shear.

(8) **The dispersion co-efficient.** It has already been shown that an equation of the Einstein type, involving only the volume of the suspended particles, is of little value in calculating the relative viscosity of a suspension; as the same volume concentration of particles in two different oils of the same viscosity yield suspensions of totally different relative viscosities. It is also a well established fact that very small additions of a third component to a suspension of fine particles in a medium may alter the value of the relative viscosity by a factor of 10, 20 or 50 or more. There must therefore exist some property of the liquid phase which determines the value of the relative viscosity—or more correctly some inter-relationship between liquid and solid. Such a relationship may be determined by the interfacial tension but, so far, we do not possess any definite knowledge. For the present, therefore, we will refer to this factor as the dispersion co-efficient of the liquid for the particular solid; a high dispersion co-efficient yields a dispersion of low relative viscosity, and a low disperson co-efficient to a high relative viscosity. For example, two parts of a titanium white dispersed in one part of refined linseed oil yielded a suspension with a relative viscosity of 105 at a certain rate of shear; whereas two parts of the same TiO_2 dispersed in one part of a polymerised stand oil gave a relative viscosity of 7.5 at the same rate of shear. The refined linseed oil has therefore a low dispersion co-efficient for TiO_2 but the polymerised stand oil has a high dispersion co-efficient. It should be possible to evaluate the dispersion co-efficient in quantitative terms by rheological methods but the problem is one of extreme difficulty as both volume concentration and rates of shear are significant variables influencing the value of the relative viscosity. Although we cannot, at present, evaluate dispersion co-efficients in quantitative terms we can say that a medium, A, has a higher dispersion co-efficient than medium B and we are thus able to study the comparative values of the dispersion co-efficients of various media and the effects of a third component upon these values.

The variations in the values of dispersion co-efficients are illustrated very clearly in Figure 11 which shows the effects obtained by dispersing 2 parts of zinc oxide in 1 part of a medium composed of polymerised stand oil and di-butyl-phthalate. The viscosities of the suspensions were measured at three different rates of shear and the curves illustrate that the

relative viscosity decreases rapidly with increasing proportion of polymerised oil; in other words, the polymerised oil has a much higher dispersion co-efficient than di-butyl-phthalate.

The relative viscosity curves obtained at the three different rates of shear show that the dispersions are anomalous fluids, and that as the proportion of polymerised oil is increased the curves gradually approach each other. In other words, the degree of structure gradually decreases with the increase in the proportion of polymerised oil. At a concentration of 100% polymerised oil the three curves coincide and therefore the system is completely dispersed.

We can apply this method to a solution of the problem of the type "What proportion of polymerised stand oil of 40 poises is necessary to disperse 2 parts by weight of TiO_2 in refined linseed oil?" It is only necessary to prepare media composed of 5% stand oil, 15% stand oil, 25% stand oil, etc., grind the requisite amount of TiO_2 in each medium and determine the viscosities of the dispersions in the Couette viscometer at the three rates of shear. Figure 12 shows schematically the results obtained. It will be seen that at a proportion of about 27% stand oil and 73% linseed oil the three curves coincide and with further additions of stand oil the relative viscosity remains constant. At this concentration of stand oil therefore the pigments are completely dispersed. Such a dispersion would, in the course of time, lead to a hard settlement so that it is advisable to use only about 25% of stand oil.

These two sets of curves illustrate clearly that the relative viscosity of the suspensions cannot be related to the viscosity of the dispersing liquid. The relative viscosity is determined by the factor we have described as the dispersion co-efficient and is a function not of the liquid alone but of the inter-relationship between the liquid and the particles of the dispersed solid.

The value of the dispersion co-efficient is the predominant factor in determining the relative viscosity at a definite rate of shear. Its importance is most easily seen in the study of dispersions in water by the effect of traces of added electrolytes; for example, the addition of a trace of sodium silicate to a 50% suspension of Kaolin in water converts it into a free flowing liquid from which a hard coherent layer settles after several hours but a proportion remains in suspension in active Brownian movement. If, however, to the original suspension traces of calcium chloride are added the system is precipitated and a soft settlement appears on the bottom of the container.

These principles find extensive applications in industry and are of great importance in processes involving the fine grinding of materials. For example, if one attempts to grind calcium

carbonate, dispersed in water, in a pebble mill, one obtains a thick fluid of very high viscosity indicating that the particles are completely precipitated. If, however, one adds 1.0% by weight of Calgon on the calcium carbonate the viscosity is considerably reduced and the suspension becomes a free flowing liquid. This change in viscosity is, obviously, an important factor in the power consumption of the pebble mill. The particles have been peptised and they can be separated into a number of fractions

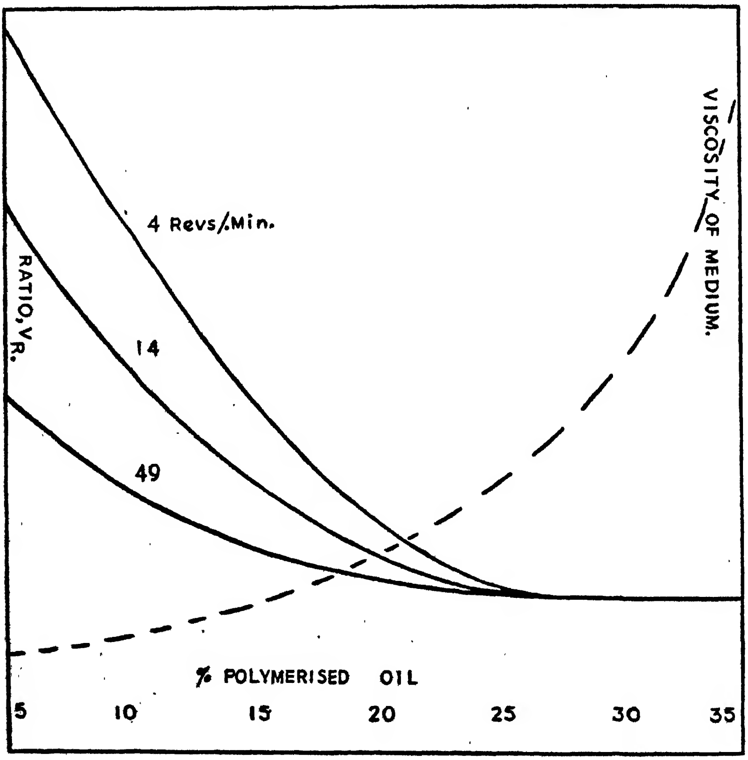

FIG. 12.

by sedimentation under gravity for increasing periods of time. For example, a period of 5 hours would produce a hard settlement of average particle size 10 mu; the supernatant liquid is now run into another vessel and allowed to settle for 15 hours yielding a settlement of average particle size of 6 mu. The process could be contained to obtain further fractions of smaller particle size until those remaining in suspension are 1 mu or less in diameter. This fraction could be recovered by precipita-

tion with traces of aluminium sulphate or calcium chloride and the resulting precipitate filtered. Similar processes, based on the selection of the appropriate peptising and precipitating agents, find many applications in the pigment industries. The shade of a pigment is a function of its particle size so that numerous shades can be obtained from a parent material by grinding and separation of the assembly of particles according to their size.

The efficient grinding of calcium carbonate depends upon the selection of the correct dispersing agent, but the preparation of satisfactory coal-oil fuel depends on the selection of the correct precipitating agent. Suspensions of finely divided particles of coal dispersed in fuel oil have been used as a fuel; in this way one obtains a suspension which is in the peptised condition so that the fine particles settle in the container to form a hard coherent layer. It is therefore necessary to add a controlled amount of a precipitating agent which imparts thixotropy or a certain degree of structure to the suspension so that the coal-oil remains homogeneous. It has been possible to select the correct reagents and satisfactory suspensions, stable over long periods, have been produced.

Another interesting problem concerns the flow of cement slurries composed of clay and calcium carbonate mixtures dispersed in water. Such a system is usually in the precipitated state and therefore of high viscosity, hence considerable amounts of power are consumed in pumping such a highly viscous material through pipes of reasonable diameters. By the selection of the correct dispersing agents it is possible to reduce the viscosity very considerably and even possible to increase the solid content and still obtain a less viscous suspension—this means a reduced water content and less fuel consumption for a greater yield of calcined cement.

We have already referred to the necessity of selecting the correct dispersing agent for any particular colloid system. Herein lies one of the principal difficulties of applying the methods of colloid science to industrial practice. A great number of peptising agents are highly " specific " in their actions; the ideal agent for dispersing Kaolin may be useless for dispersing carbon black, or the ideal agent for carbon black may be useless for dispersing cement or even coal dust. Colloid chemists are always interested in " specificity of action " for it must be based on some fundamental principles which, in this instance, still remain to be discovered.

As the selection of the correct dispersing agent is such an important factor in the study of suspensions the following table, taken from a recent paper ([14]), has been included as representing some typical dispersing agents for a range of familiar materials.

Dispersing Agents in Common Use.

Liquid Medium	Dispersing Agent	Suitable For
Water	Aerosol OT $\frac{1}{2}$% by vol. Sodium linoleate ... Sodium arsenite ... Sodium pyrophosphate 0.005 mol./L. ... Sodium silicate 2% ... Potassium citrate 0.1 gm. mol./L. ... ... Sodium oxalate N/100	 Coal; graphite. Iron oxide. Silica; silicates; sillimanite; zircon Chalk. Mineral colours: Soils; clays.
Alcohol	—	Coal; cements.
50% Alcohol-water	—	Silica; silicates.
Alcohol-glycol ...	Potassium citrate ...	Stucco-plaster.
Isobutyl alcohol or diethyl ester of phthalic acid ...	—	Organic powders; starches; flour; sugar; cocoa; lignite.
Ethylene glycol ...	— Cobalt chloride ... Cobalt citrate	Cements; burned magnesite; Alumina cements: Gypsum.

(It should be emphasised that the selection in the above list was made for the particular purpose of obtaining suspensions, with the highest degree of dispersion, for measurements of particle size.)

So far only passing references have been made to dilatancy but it is of interest to determine whether the value of the dispersion co-efficient bears any relationship to the development of this property frequently found in colloidal suspensions. The sand on the sea-shore, left moist by the ebbing tide, becomes firm and dry under the pressure of a foot but when the pressure is removed the sand becomes moist once more. Uniform sand grains normally settle in a state of close packing; that is the state where one sphere touches 12 neighbouring spheres if all the grains are spherical. If such an assembly of particles is sheared the particles must separate and hence their volume must increase before they can slide over one another. As they are sheared they assume the state of more open packing—in which one sphere may touch 10, 8, 6 or 4 neighbouring spheres. In close packing the volume of solid is 74% and of the voids 26%; but in the most open packing the volume of the solid is 34% and of the voids 66%. It is therefore evident that moist sand in close packing will become dry on shearing as the amount of

moisture present is not sufficient to fill the voids. This property was called " dilatancy " by Osborne Reynolds ([15]) because a granular medium expands when it is sheared laterally.

The change from closed to open packing does not offer a complete explanation of dilatancy because this property can be frequently observed in suspensions where the volume of the solid does not approach 74% by volume. This is true, for example, of maize starch in distilled water which is highly dilatant at concentrations of 50% by volume. It may be argued that a " hydration factor " influences the effective volume, but this argument cannot be applied in general—for example, to smalts particles which consist of cobalt potassium silicate glass. Smalts particles, averaging 20 mu to 25 mu in diameter, dispersed in water at a volume concentration of 45%, yield a highly dilatant paste. If it is gently vibrated in the palm of the hand it flows freely but if one attempts to close the hand the system becomes a rigid solid which breaks into small fragments or crumbs, but on opening the hand it flows freely once more. Numerous other systems which show dilatancy at a volume concentration below 74% could be quoted. Therefore the simple theory of the change of packing does not account for this phenomenon. It is probable that a complete explanation could be found from a study of the distribution of particle size of the irregular grains, and from the effects produced as a single grain reduces its number of contacts from 12 to 8 to 6 or to 4 of its neighbours.

It is therefore evident that the characteristic feature of dilatant systems is their increase in viscosity with increasing shear. A typical curve is shown in Figure 3 by the curve *ABCDE* obtained by means of the twin-Couette viscometer. There is a rapid increase in viscosity with increasing rate of shear beyond the critical value represented by the point *C*. As the rate of shear increases beyond the range of the point *E* the system breaks up into crumbs and no further observations are possible. There is some evidence that at low rates of shear dilatant systems show some indication of anomalous viscosity as can be seen in the portion *AB* of the curve. Further, some systems " shear harden " under constant rate of shear if applied for a considerable time at a value just below the critical rate of shear.

As in the study of thixotropy it is better to regard the phenomenon as the " dilatant state " rather than regard dilatancy as a peculiar property of certain materials in the finely divided condition. As thixotropy is determined by the colloidal environment of the particles so is dilatancy dependent upon the medium in which the particles are dispersed. It is a compar-

atively easy matter to impart either thixotropy or dilatancy to the same material by the appropriate selection of the dispersing medium and the concentration of the particles. Thus maize starch is dilatant in water but is thixotropic in carbon tetrachloride or toluene. Barium sulphate dispersions are thixotropic in liquid paraffin but are highly dilatant in polymerised oil of 80 poises viscosity under the appropriate solid concentrations.

There is a great deal of evidence that dilatancy is observed only in liquids with a high dispersion co-efficient. (This generalisation is not universally true; it is possible to obtain dilatancy due to close packing alone in liquids of low dispersion co-efficients but if we limit our attention to those systems in which the solid concentration is well below the critical volume of 74% the phenomenon is observed only in dispersions with a high co-efficient, such systems are quite abundant in practice.) We have already seen that complete dispersion of particles, at a low solid concentration, in a liquid leads to a hard compact settlement—that is an assembly of closely packed particles, approaching the critical volume of 74%. On the other hand partial dispersion or precipitation of particles, at low solid concentration, in a liquid yields a soft settlement, or an open structure of low solid concentration. Similarly, if the solid concentration of a suspension in a liquid with a low dispersion co-efficient is gradually increased a stage is reached where the system becomes highly thixotropic; a further increase in the solid concentration does not lead to dilatancy but increases the degree of thixotropy. If, however, the liquid has a high dispersion co-efficient one can increase the solid content until the system becomes dilatant but without the development of thixotropy at any concentration of the solid. For example, 1 part of ultramarine in 1 part of di-butyl-phthalate is highly thixotropic; but 1 part by volume in 1 part of blown castor oil is not thixotropic. If the proportion of ultramarine is increased to 1.7 parts by volume to 1 part of blown castor oil the system is highly dilatant. Independent experiments prove that di-butyl-phthalate has a low co-efficient of dispersion and blown castor oil a high co-efficient. Similarly equal volumes of ultramarine and a lithographic varnish of 100 poises viscosity, with a high dispersion co-efficient, yield a very highly dilatant printing ink. The dilatancy is so pronounced that the ink "crumbles" into small fragments under the high rate of shear between the rapidly rotating rollers of the printing machine but the ink flows anew when the rollers come to rest.

We may therefore conclude that the dilatant state is induced in suspensions of high solid content in liquids of high dispersion co-efficient; and from the evidence given in the

preceding pages, that the degree of dispersion of fine particles in the five rheological states increases in the following ascending order: —

Degree of Dispersion.

Anomalous viscosity → "False Body" → Thrixotropy
→ Dilatancy → Newtonian Flow.

This lecture represents one aspect of rheology, namely the study of the factors which influence the relative viscosity of suspensions of fine particles in fluids, and its closely related problems the measurement of the dispersion co-efficient of the fluid and the measurement of the degree of dispersion. It will be realised that the study of these subjects is still in its early stages but that it deserves the attention of colloid chemists and rheologists. No reference has been made to the important problem of formulating the laws of flow of non-Newtonian fluids in general but the recent intensive experimental and mathematical developments in rheology indicate that these important laws will in time be established on a sound foundation.

J. PRYCE-JONES.

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LECTURE ON "THE RHEOLOGY OF PLASTIC SOLIDS"

GIVEN BY

G. W. SCOTT BLAIR, M.A., Ph.D., D.Sc.

(February 1st, 1946).

I am glad that the Philosophical Society should have chosen Rheology as the subject of this course of lectures because I believe that this particular branch of Natural Philosophy has not, in the recent past, received the attention it deserves. Interest in the physical sciences has not unnaturally been focussed on more spectacular fields, such as the large-scale production of energy by atomic disintegration and the fascinating speculations concerning the nature of matter and energy associated with it; or the synthesis of tailor-made materials for industry, the theoretical aspects of which have been perhaps mainly concerned with organic chemistry.

Likewise in psychology, the spontaneous reaction to the great discoveries of Freud and others on the unconscious has tended to obscure the importance of psycho-physics, a science which has an intimate bearing on rheology.

Since it is my privilege to give the first of these lectures, I may perhaps be allowed to spend a few moments discussing the background of rheology as a whole before turning to that special field which has been allotted to me. This is not through any desire to spend time on high-brow speculations instead of getting down to discuss very mundane materials—literally, "of the earth, earthy"—but because the early history of rheology echoes this very point. It was none other than the great *anti*-rheologist Parmenides who rebuked the young Socrates for refusing to be interested in "hair or mud or dust or any other trivial or undignified objects"—objects of special interest to modern rheologists—although Parmenides himself was so convinced of the illogicality of the conception of unoccupied space without which motion was impossible, that he was obliged to deny motion altogether and declare all rheological phenomena as illusory.

The theories of his opponent Heraklitus, in spite of the often quoted πάντα ῥεῖ, are linked with modern rheology more through, as an intermediary, such concepts as Bergson's "Durée", than in the strictly mechanistic way in which the saying is often interpreted.

Socrates, then, preferred to think only of sublime things and he, Plato and others laid the foundations of that curious myth of "pure science" which has been so prevalent among us until recent times.

I have no time now to speculate as to what might have happened if modern science had grown from Indian roots which were much less corrupted by such ideas or whether the Theory of Forms has done more good than harm in the development of Physics. Suffice it is to say that the dead hand of Plato still rests heavily on the rheologist—perhaps more so than is the case in many other branches of Science because perfectly elastic solids and perfectly viscous liquids are much more nearly the objects of everyday experience than are, for example, hundred per cent extroverts or perfectly economic men. Or to take an illustration from astronomy, stars do not fall precisely into the ten categories of the Harvard Spectral classes.

As early as 1660 Hooke found objects which, like springs, extend by an amount proportional to the applied force and in 1685 Newton first formulated, and in 1687, published the concept of a liquid which should flow at a steady rate at constant pressure and such that the rate is proportional to pressure. Because piston-cylinder devices are used by engineers to damp vibrations in some kinds of machines under the title of "dash-pots", the "forms" of perfectly elastic and viscous behaviour are commonly referred to as "springs and dashpots." The "form" for a static friction, typified by a weight being pulled horizontally along the surface of a table, we will call a "slider."

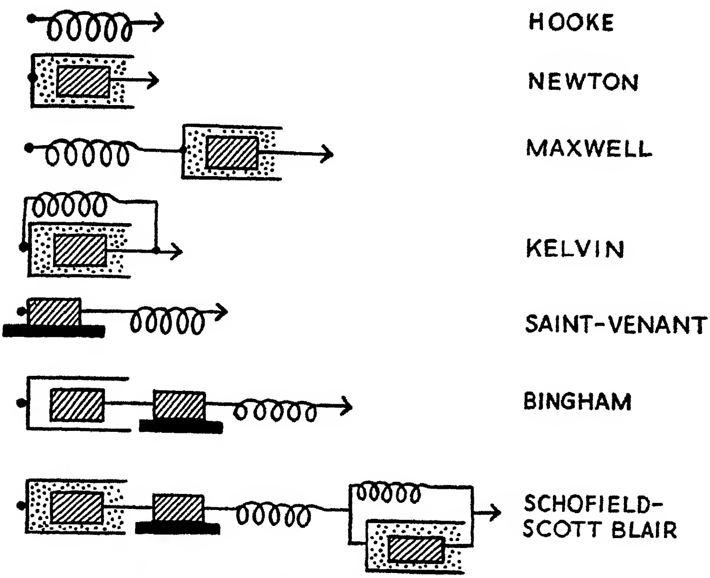
Now it has been found possible to explain the relationships between deformation, time and load for very many complex materials by means of models made up of springs, dashpots and sliders in series and in parallel and this treatment forms the basis of which has come to be known as "analytical" rheology because it analyses the behaviour of complex materials into independently acting simple components.* In some cases, it is claimed that the material is actually composed of molecular species which really do behave like springs and dashpots: in others, and more frequently of late, the description is not supposed to imply that such elements exist, but only that the behaviour of the material can be described by the simple exponential equations which the less complex of these models provide. These fit very simply into the framework of classical physics, since the behaviour of the materials can be described by a series of constants all of which have the dimensions of an elastic modulus or yield-stress ($ML^{-1}T^{-2}$) or of a viscosity ($ML^{-1}T^{-1}$).

The simplest of these groupings are generally associated with the names of those who first proposed the use of the equations to which they correspond. They have been very

*There are, of course, other prototypes, such as Meyer and Ferri's "perfect elastomer" (1)

effectively tabulated by Reiner (2) and I owe the design of Fig. 1 to his papers.

For certain rheologically complex systems, such as muscle, very complicated dashpot-spring models have been proposed.



ANALYTICAL PROTOTYPES FOR ELASTIC AND PLASTIC MATERIALS (MODIFIED FROM REINER.)

FIG. I

The use of the models themselves was by no means always proposed by the original authors. Thus, although it is true that Maxwell postulates elsewhere (3) a two-phase structure for materials which show an exponential relation, in the paper in which relaxation times are defined (4) he makes no mention of dashpots and springs. As his biographer Crowther puts it, (5) "Though Maxwell could use engineering images with at least as much power as any of his contemporaries, he was entirely free from the tendency to assume that they were necessarily more real than mathematical symbols and so he escaped the chief error of the scientific philosophy of the nineteenth century." What in fact Maxwell did do was to make the simplest possible assumption about the rate at which stress would dissipate in a system held at constant deformation, i.e. at a rate proportional

to the stress itself. This leads to the very simple equation

$$-\left(\frac{\delta S}{\delta t}\right)_{\sigma} = \frac{S}{t_r}$$

where S is stress, t is time and t_r is the constant relaxation time.

but, since bodies of the Kelvin type were already known, he freely admitted that relaxation times might well turn out to be not independent of stress and, in the majority of cases, this has been proved to be the case.

An alternative way of studying the problem is to classify the types of deformation which are actually produced, in accordance with whether they are recoverable and, if so, whether recovery is immediate; whether the deformation is simply proportional to the applied stress or not; whether the deformation changes at a rate which increases or decreases under constant stress; whether there is any clearly-defined stress below which no permanent deformation occurs, etc. A number of tables have recently been published classifying deformations in this way.

Our subject this evening, the Rheology of Plastic Solids, is concerned with materials which are represented by models containing sliders, the simplest of which is the Saint Venant body, but the least complex model which corresponds to any large number of real materials is the Bingham body. Thus many pastes of clay, soils, mud, dentifrices and some paints do not deform appreciably until a limiting (yield-value) stress is reached (the modulus of the spring in the model being high) and thereinafter flow at a rate proportional to the excess of stress over yield-value.

A reasonable atomic picture to illustrate this behaviour is given in a diagram which has been used by a number of authors and especially clearly explained by Houwink, whose book ([6]) I am here paraphrasing.

The forces which account for the cohesive properties of solids must be regarded as the resultant of attractions and repulsions between atoms and it is known that the repulsive forces, although enormous at short range, fall off much more rapidly as the atoms separate than do the attractive forces. There will be a certain distance (marked "a" in Fig. II at which these forces cancel and the atoms are in equilibrium. If the atoms are separated with forces less than that corresponding to the height of their maximum above the axis, the material suffers an elastic displacement, the modulus of elasticity being given by the tangent to the curve. If, however, a stress greater than this is applied, the material will suffer an irreversible displacement, either breaking or, if the energy can be dissipated fast enough by flow, flowing like a liquid.

The above treatment is really an oversimplification since it depicts the primary atomic bond such as that binding Na and Cl ions in NaCl or the homopolar bond as in H_2. In most of our rheological processes we are mainly concerned with the weaker secondary bonds but similar principles apply. Freundlich claims that in thixotropic systems, attractive forces are felt over distances of the order of 0.1μ.

FORCE-AND POTENTIAL CURVES BETWEEN TWO ATOMS

(DIAGRAMMATIC — AFTER HOUWINK.)

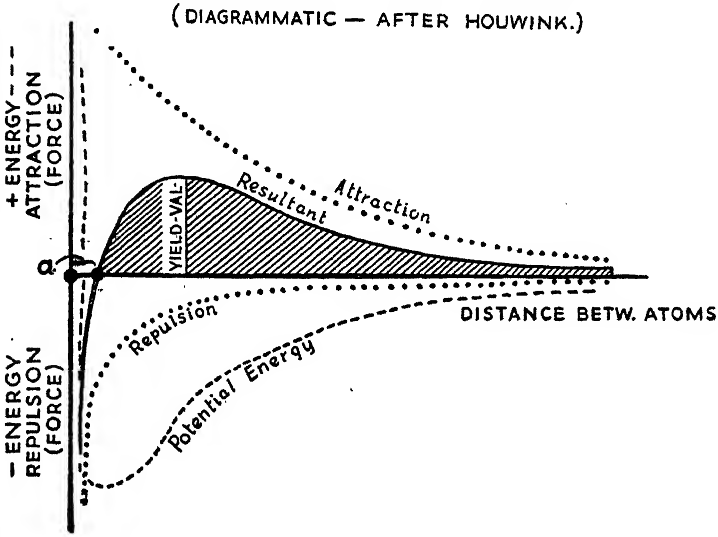


FIG. II

If we plot the potential energy as the atoms approach one another, this, starting from zero at infinite distance, will increase in a negative sense as the shaded area in the diagram (which is a measure of the energy) increases, giving a point of inflection at the yield-value where the rate of increase starts to fall) and finally passing through a sharp minimum at the equilibrium point. The value at the minimum depends on the work required to bring the atom from infinite distance up to the point of equilibrium. This energy curve is shown on the diagram as a broken line.

When we come to consider secondary forces quite elaborate energy curves have been postulated. These depend in general on the assumption that, whereas attractive forces of the van der Waals type are independent of ions in the neighbourhood, the

repulsive forces, arising from the electrical double layers, are much influenced by them. The effects of electrolytes on the stability of sols and suspensions can be explained in this way.

Moreover, in the case of non-crystalline materials, the potential troughs are not regularly spaced nor are they of even depth, hence the forces needed to draw the atoms out of their equilibrium positions will vary considerably and we shall find all degrees of behaviour from the solid, showing a clearly defined yield-value at one extreme, to the true fluid at the other. A number of authors have considered the case of a weak energy minimum at a comparatively large distance as typical of thixotropic behaviour. The molecules or other primary particles gradually settle into this stable configuration but are easily shaken out of it and only return gradually on account of the viscous resistance of the medium.

Hamaker (7) has formulated distinctive groups of curves to represent lyophobic and lyophilic conditions respectively and one is reminded of Pryce-Jones's distinction on these lines between thixotropy and false-body. Perhaps he will speak about this in his lecture in this series.

I have no time this evening to discuss the mechanism of liquid flow except to say that whereas at one time (probably because liquids and gases are both " Newtonian ") the analogy with gases was stressed, liquids are now thought of rather in their relation to solids. Flow is usually regarded as analogous to a chemical reaction in which molecules change partners and, as Parmenides foresaw, empty spaces are needed for such exchanges to be possible. The fluidity of the liquid (i.e. the reciprocal of viscosity) is supposed to depend on the number of these holes. Thus the analogy between liquids and gases is an inverse one, the liquid consisting of holes moving about in a " solid " continuum. This leads us to the A.S.T.M. definition of a plastic solid as " a substance which does not deform under a shearing stress until this stress attains the yield-stress, when the solid deforms permanently ". This is seen to include the Saint Venant and Bingham bodies as well as the more complex models. But in the case of the last the relative importance of the different units has to be taken into account, and in deciding, for the purposes of this lecture, what are and what are not plastic solids, I am faced with considerable difficulties.

For example, the model marked " Schofield-Scott Blair " represents Reiner's interpretation (slightly simplified) of our experiments of flour doughs (8). To most of us, a flour dough, or at any rate a " springy " flour dough for bread-making as distinct from a biscuit dough, for example, would suggest an elastic rather than a plastic solid. A paint or a clay paste which

RHEOLOGY OF SOME PLASTIC SOLIDS—TYPICAL METHODS OF TESTING.

†PLASTO-ELASTIC (METALS TO ASPHALTS AND BITUMENS); †PLASTO-INELASTIC (SOILS TO PAINTS, ENAMELS, ETC.)

MATERIAL	SOME IMPORTANT "PROPERTIES"	CAPILLARY TUBE	JET-ORIFICE	ROTATION APPARATUS	SPHERES (RISING FALLING, ETC)	"SINKER" TYPE TESTS	WORK OF STIRRING	BUBBLE METHODS	PENETROMETERS	EXTENSION OR COMPRESSION OF TEST-PIECES	BENDING OR TORSION OF TEST-PIECES	SECTILOMETERS	INDENTATION HARDNESS TESTING	WEIGHT OR BALL DROPPING TESTS
METALS	*													
WOOD	STRENGTH COMPRESSIBILITY SWELLING-PROPS., ADHESION									DE BRUYNE BULL LISKA PRYOR	DRAFFIN-MUHLENBRUCH HEARMON NEWLIN-TRAYER		McBURNEY	
BONE	STRENGTH										BELL-CUTHBERTSON-ORR			
RUBBERS AND PLASTICS (SHOWING CREEP)	HIGH-ELASTICITY DUCTILITY STRENGTH RELAXATION SPRING DISSIPATION COEFFICIENT	BURNS COUZENS-WEARMOUTH FOOTE PENNING-MEYER WEARMOUTH-BERENBLUT WIGGAM	DILLON-JOHNSTON MARZETTI NASON PENNING-MEYER SCHULTZ-BRYANT SCOTT	DILLON-COOPER FERRY MOONEY PIPER-SCOTT TAYLOR			SHOAFF SPEITMAN		OWEN SAXL ZEBROWSKI	BILMES BUIST-SEYMOUR HAWARD HOUWINK SCOTT WILLIAMS	BARRON BILMES CLASH-BERG OWEN REISS		BARRON BOOR HICKMAN KLINE-AXILROD OWEN SCOTT	BARRON CHURCH-DAYNES LUBIN-WINANS SANG TELFAIR-NASON WILLIAMS
ASPHALTS AND BITUMENS	CONSISTENCY COVERING POWER ELASTICITY DISSIPATION COEFFICIENT	LEE-WARREN SAAL	HORSFIELD	FORD-ARABIAN KOROTKEVICH LEE-WARREN ROSSI SAAL-LABOUT	BROOME-THOMAS HÖPPLER WALTHER	PENDLETON POCCHETTINO PUGH TRAXLER-SCHWEYER			DAVEY MACK MILL-HARRISON PENDLETON PFEIFFER-DOORMAAL TRAXLER-MOFFATT	BROOME-BILMES LETHERSICH VOKAC	LONSDALE-WILSON	LYON-VOLD	McBURNEY	MANTON-WREN
FLOUR DOUGHS	BODY SPRING RELAXATION	VOLAROVICH	STAMBERG-BAILEY	DRANOPOL'SKAYA HENDERSON-FENN-COHN VOLAROVICH ET AL.			BAILEY ET AL. BRABENDER DIEDE RING KÖSTER MALLOCK SWANSON ET AL.	BAILEY ET AL. CHOPIN DE REGE SAUER SWANSON	VAN DER LEE	BOHN-BAILEY HALTON-SCOTT BLAIR ISSOGLIO KOSUTÁNY SAUER SCHOFIELD-SCOTT BLAIR			KOSUTÁNY	HARREL ISSOGLIO SCHOFIELD-SCOTT BLAIR
CHEESE	BODY SPRING WORK HARDENING		ROGERS-SANDERS		SCHWARZ-FISCHER			ROGERS-SANDERS	KOESTLER ROUNDY-PRICE SAXL	CAFFYN DAVIS KOESTLER SCOTT BLAIR-COPPEN		CAFFYN COPPEN ROGERS-SANDERS	CAFFYN SCOTT BLAIR-COPPEN ROUNDY-PRICE	
BUTTER AND MARGARINE	HARDNESS FALSE-BODY YIELD-VALUE SPREADABILITY		SARGENT						GALLUP-KUHLMAN-WALDBY KRUISHEER ET AL. MULDER PERKINS WECKEL	DAVIS DOLBY HUNZIKER-MILLS-SPITZER LYONS SCOTT BLAIR		COULTER-COMBS DOLBY MOHR MULDER ET AL. WECKEL		LEXOW
GREASE	STIFFNESS FALSE-BODY LUBRICATING QUALITY	ARVESON BLOTT-SAMUEL MERRINGTON REBINDER ET AL. VARENTSOV-VELIKOVSKII		PETHRICK	HÖPPLER				KAUFMAN-FINN-HARRINGTON WEBBER	ROLLER				CAMERON COMBES-FORD-SCHAER MARTEL
STARCH PASTES	CONSISTENCY FALSE-BODY PRESSURE-COEFFICIENT	BRIMHALL-HIXON FARROW-LOWE-NEALE GEINITZ HERSCHEL-BERGQUIST PORST-MOSKOWITZ		ANKER-GEDDES BARHAM ET AL. BRIMHALL-HIXON FARROW-LOWE-NEALE HÖDER	KRUYT-SELMS RÖDER		ANKER-GEDDES CAESAR			NEALE ■				
CLAY (THICK PASTES)	BODY PLASTICITY WORKABILITY	CUNNINGHAM ERBRING ET AL. HOBSON RICHARDSON SCOTT BLAIR-CROWTHER SHEARER	BLEININGER-ROSS KEPPELER-GOTTHART	ERBRING ET AL. MUKHERJEE ET AL. NORTON ET AL. RICHARDSON KOLLER-STODDARD VOLAROVICH ET AL.	BAUER BROUGHTON-WINDEBANK SEMBACH				ACKERMANN	HIND MACEY ROLLER RUSSELL-HANKS THIEMECKE	NORTON PARMALEE-RUDD PFEFFERKORN WEBB			BOWMAKER MEHR-IMMKE KRATZERT PFEFFERKORN
SOILS	TILTH FLOCCULATION CONDITION CRUMB-STRUCTURE	KEEN-SCOTT BLAIR		RICHARDSON			RHODES		ALLYN-WORK JACKSON	HOGENTOGLER-BARBER			BALLU BURMISTER ‡ CULPIN POKROVSKII ET AL. TERZAGHI SCOTT BLAIR-CASPERS	KNEAS
PEAT	?	KULAKOV ET AL. VOLAROVICH ET AL.		KULAKOV ET AL.	KULAKOV									
DRILLING MUDS	STABILITY PLASTERING CAPACITY THIXOTROPY	AMBROSE-LOOMIS EVANS-REID MUKHERJEE ET AL.		AMBROSE-LOOMIS COLLOM EVANS-REID		EVANS-REID								
CHOCOLATE	BODY COVERING POWER	CAMPBELL CLAYTON ET AL.												
FRUIT AND VEGETABLES	FIRMNESS								CAMPBELL ET AL. BONNEY-CLIFFORD-LEPPER JENKINS-LEE LANDRETH SWEETMAN-LANCASTER					
PAINTS, ENAMELS, ETC.	CONSISTENCY COVERING POWER BRUSHABILITY FALSE-BODY LEVELLING PROPERTIES	BINGHAM ET AL. GAMBLE HARRISON KEWISH-WILCOCK MARDLES McMILLEN	GAMBLE	GAMBLE MARDLES PRYCE JONES RICHARDSON VOLAROVICH ET AL. WELTMANN ET AL.	KEWISH-WILCOCK LEVIN MARDLES RÖDER WACHHOLZ-ASBECK	DROSTE WACHHOLZ-ASBECK				BIANCHI-WEIHE ■ MATTHYSEN NELSON RUNDLE-NORRIS				

* DEALT WITH IN A SUBSEQUENT LECTURE
† NO HARD-AND-FAST DEMARKATION
‡ COMPRESSION OF SOIL IN SITU
■ DRIED FILMS

FIG. III

might follow the Bingham law very accurately, would hardly be thought of as a "solid" at all.

But the dough is plastic, in the sense that under the right conditions it shows a clearly marked elastic range, and the paste is solid in the sense that it shows a definite rigidity, tolerating small shear stresses without yielding. The former is thus classified as a plasto-elastic system and the latter as plasto-inelastic.

In order to give you some idea, however sketchy, of the range of plastic solids which have been studied and of the methods used for this purpose, I have attempted to make a table (Fig. III) showing something of the scope of the literature. For reasons of space, I have been obliged to exclude a good many materials and some of the less important testing methods, and in a few cases the authors quoted *describe* methods of testing materials, not actually having done the experiments themselves. I have also limited myself to a maximum of six investigations under any one heading, although in some cases this has meant ignoring quite important researches. The selection which I have made is bound to be somewhat arbitrary and is not meant to suggest any judgment on the relative merits of the investigations; so please do not be upset if some article you may regard as fundamental has been omitted. Apart from considerations of space, I may well also have overlooked important researches in materials with which I am not personally familiar.

I had originally intended to include glass as a plastic solid; but, although glass certainly shows plastic properties at certain temperatures, I was convinced, after hearing Dr. E. Preston's recent very able lecture to the British Rheologists' Club, that it is fairer to regard glass as primarily an elastic liquid, a category which is being dealt with by another lecturer in this series.

The first point which the table clearly illustrates is the very general use to which certain well-known methods can be put, indicating the necessity for every practical rheologist to keep closely in touch with the literature for materials which may seem very different from his own. As an illustration, may I take my own case? We are at present engaged in a Meyer analysis of Brinell tests on cheese.

Keeping in touch with work on other materials is at present by no means easy on account of the very wide range of technical journals in which the rheology of industrial materials is discussed. This is also why, in spite of a natural reluctance to start still more scientific organisations and journals, such bodies as the (American) Society of Rheology, the British Rheologists' Club, the Committee for the Study of Viscosity of the Dutch Royal

Academy of Sciences and the Section of the Academy of Sciences of the U.S.S.R. which deals with Rheology, are so necessary if we are to benefit by the experience of colleagues who work in fields other than our own.

Very broadly, I have arranged those methods which are generally suitable for materials of low consistency on the left of the table, with those suitable for hard materials on the right. One could hardly test clay slips with a Brinell hardness tester, or wood by flow through capillary tubes!

It is also clear that different methods measure different properties and you will notice that I have written " Properties " in the table heading in inverted commas, since many of the " properties " of materials which are of the greatest importance in Industry are not strictly physical properties in that they cannot be expressed, nor will they ever be expressible, in terms of integral or even invariable powers of mass, length and time, except in limiting cases. I propose to deal with these important entities rather fully elsewhere. Some of them are reproducibly and accurately measurable in certain cases even when quite different methods are used, being in this respect similar to true physical properties: others, although reproducible if the same test is applied, are not apparently independent of the method of measurement.

Since the definition of a plastic solid implies a sharply-defined stress below which the material does not show permanent set and above which it flows, I have used, in this lecture, mainly the analytical approach which divides deformations into clean-cut elastic and plastic components. In other branches of rheology, this procedure is often not practicable; and even among the plastic solids there are cases, where, above the yield-value, the rate of flow varies smoothly with stress and many more in which it is not constant for a constant stress but progressively increases or (more often) decreases with time.

The simplest expression for this type of behaviour is a power-law relation between stress (S) strain (σ) and time (t) which, first proposed by Nutting (9) is now usually written:

$$\psi = S^{\beta}\sigma^{-1} t^{k}$$

For plastic bodies, this must be amended to include a yield-stress $\psi = (S - S_0)^{\beta}\sigma^{-1} t^{k}$

For the case when $k \sim 1$, this is identical with the Herschel-Bulkley equation (10). The stress exponent is of importance for systems such as starch pastes and k (which is known as the " dissipation coefficient ") for many bitumens and plastics as well as for cheese.

It is now believed that this type of equation is a simplifica-

tion of a series equation of which it is the first term. The fractional differentiation of this general equation leads to a rather complex expression which seems to lie at the heart of the problem of how to treat those important entities which are not true physical properties—but that is another story.

Apart from the need for a clearly defined yield-value which, although included in the definition is only approximated in practice, the above treatment is "integralist" as distinct from "analytical" in that it studies the S: σ :t functions as a whole and without splitting them into independent parts.

It is based on what has been called "The Principle of Intermediacy" which simply means that the "properties" of complex materials are regarded as lying *between* the properties of the elastic, viscous or other perfect prototypes rather than regarding the material as consisting of a sort of mechanical mixture of elements each of which has true "physical properties" to relate S: σ :t. The treatment has the disadvantage that it is not at all easy to make models such as dashpots, springs and sliders, to illustrate it and that it deals with entities whose study lies on the borderline and often across the borderline of physics as usually defined. It has the advantages of being much simpler (for really complex systems at least) than the strings of exponential terms needed in the analytical treatment and in having close and intimate links with the psycho-physical treatment of assessments of firmness, body, spring, etc. in the handling of such industrial plastic solids as the potter's clay, the farmer's soil, cheese, etc. There are many industries in which subjective handling judgments will long continue to be used and so long as the data are properly treated statistically, the collection and correlation of such judgments constitutes a perfectly legitimate scientific procedure.

Evidence from my own laboratory shows that for materials for which $\beta = 1$, differences in handling pressure as exerted by different people squeezing various materials to compare their firmness does not influence the comparisons given. For materials like masses of clay, however, where there is a high stress exponent, comparisons between materials will only be reproducible for testers who use approximately the same squeezing pressures.

In the case of really complex systems, some analytical rheologists are forced to postulate non-Newtonian dashpots and perhaps non-Hookean springs. What can be the meaning of models constructed of such units I cannot imagine, except perhaps in the very simplest cases; as, for example in introducing a dashpot with a simple yield-value to avoid the use of sliders, but this is no more than shorthand.

The argument sometimes put forward that the analytical approach is the only correct one because, as Guth [11] puts it "We say that we understand a certain class of solids if we can set up a model which explains its characteristic properties" is out of sympathy with the whole trend of modern physics. The fact that we can make dashpot-spring models to illustrate the behaviour of a particular plastic solid over certain limited ranges of $S : \sigma : t$ is extremely important in that it enables us to classify phenomena and sometimes to predict them, but it does not in itself jusify any claim to "understand" the solid in question. Even diagrams such as that shown in Fig. II beg far too many questions to justify our regarding them as more than helpful indications of what may be happening at the atomic level.

It would be possible to draw "potential curves" to represent almost any rheological data but this is not to say that these would offer any real explanation of the phenomena.

I have talked for some time about plastic solids without any direct mention of "Plasticity." The adjective "plastic" means "mouldable" (plasticus, πλαστικὸς) and the most sensible quantitative definition of plasticity would therefore seem to be the extent to which a material can be moulded. This implies a certain initial rigidity, since it is reasonable to include the capacity to retain the moulded shape as part of the definition. It must also include sufficient cohesion for the moulding energy to be taken up in flow rather than in rupture, a factor which will depend on the rate of moulding. Presumably also the retention of form precludes cases where there is much elastic recovery.

The plasticity of clays has been measured in terms of the largest deformation which the clay mass will stand without breaking, as in the rolling out of a "wire" but it is doubtful if it is the strain so much as some factor involving the stresses which is critical. The range of moisture over which the clay is plastic will naturally influence the practical mouldability but it is hardly, in itself, a measure of plasticity. It seems likely that that entity which the practical man calls "plasticity" is closely related to the balance of yield-value and mobility in flow (*vide* my flow-plasticity test) [12] just as for the baker, the relaxation time, which is given by the ratio of viscosity to elastic modulus, is an important measure of "spring."

Conclusions

I have attempted to show in the course of this lecture a little of how Rheology is established as a branch of Natural Philosophy and, in more detail, something of the place of the study of plastic solids within the framework of rheology. Later

lecturers will deal with other aspects of the science. May I express the hope that the course as a whole will serve to introduce Rheology to a number of you and to illustrate something of the scope and interest of that branch of study which has been defined as "The Science of the Deformation and Flow of Matter"?

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ELASTIC FLUIDS

Lecture delivered by

A. C. MERRINGTON, B.Sc., Ph.D.

The previous speakers in this series will no doubt have introduced you to the science of Rheology which is concerned with a study of the deformation and flow of matter. It is obvious from this definition that rheology covers a very broad field which is becoming increasingly important in industry today. The titles chosen for this course of lectures amply confirm this view.

In the present lecture it is proposed to deal with a certain type of fluid, namely, an elastic fluid, which exhibits both viscosity (the property of a liquid) and elasticity, (the property of a solid). That such liquids exist can be shown quite simply in a number of ways. For example, if we pour a quantity of a suitable rubber " solution " into a dish, it remains in a heap and if disturbed, vibrates like the ordinary table jelly indicating that the liquid possesses rigidity. If left long enough, however, the liquid flows over the bottom of the dish finally leaving a perfectly level upper surface similar to that produced by any normal liquid.

Again, if a metal cylinder suspended by a fine wire and immersed in a viscous oil is given a twist and then set free, it will slowly and steadily return to its equilibrium position under the damping imposed on it by the viscosity of the oil. If the same process is carried out with the rubber solution in place of the oil the cylinder will not move slowly back but will immediately return part of the way towards equilibrium thus showing that part of the displacement resulted in elastic deformation.

Pryce-Jones (1) has clearly demonstrated this elastic recoil in a more complicated manner using a new rotation viscometer consisting of a double Couette instrument with the two cylinders rigidly connected and having the cups rotating in opposite directions. Castor oil is placed in one cup with 0.5% sodium alginate plus 0.1% calcium citrate in water in the other, and equilibrium is obtained with the cups rotating at appropriate speeds. If a short time after coming to rest the instrument is suddenly restarted, the cylinders show a very marked elastic recoil which was not present with normal liquids.

Non-Newtonian Liquids.

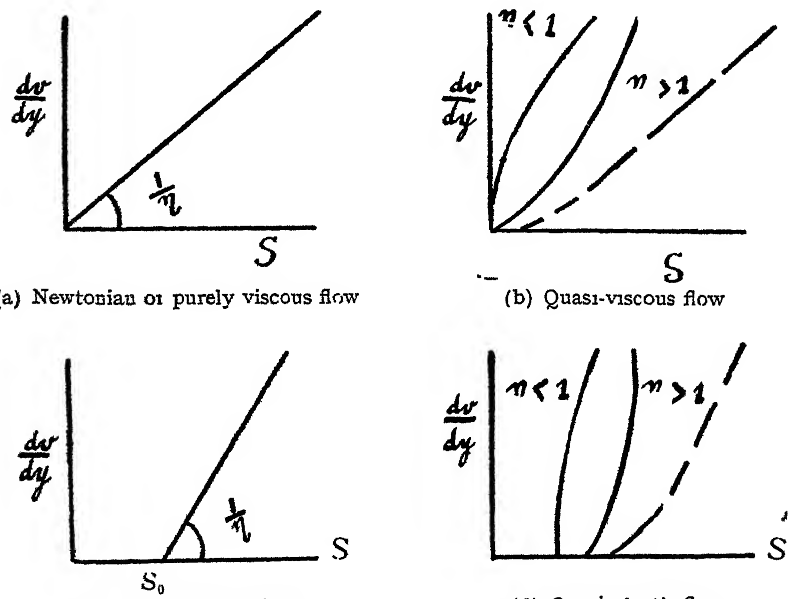
Before discussing this elastic property in more detail, however, we might for a moment go back to Newton, who, as you

all know, first postulated that in a liquid moving with laminar flow,

$$\text{Velocity gradient } \frac{dv}{dy} \propto \text{ Stress, } S$$

$$= \phi S = \frac{1}{\eta} S.$$

where ϕ is the fluidity and η the viscosity, both unique quantities for the particular liquid at any given temperature. Such liquids are termed " pure " or " Newtonian " and for these a plot of $\frac{dv}{dy}$ against S gives a straight line of slope $\frac{1}{\eta}$ as shown in Fig. 1 (a); such curves may be obtained experimentally. It should be noted here that we are confining our remarks to laminar flow so that turbulence is excluded.



(a) Newtonian or purely viscous flow (b) Quasi-viscous flow

(c) Purely plastic flow. (d) Quasi-plastic flow.

FIG. 1.

In contrast to Newtonian behaviour, we have the so-called " non-Newtonian " liquids in which the linearity described above is no longer true. We must consider this non-Newtonian type of flow in more detail since many liquids which behave in this manner also exhibit elasticity.

In non-Newtonian flow, then, $\frac{dv}{dy}$ is no longer pro-

portional to S, but is some other function of stress. There are many ways in which the curve may deviate from linearity and some of these are included in Fig. 1.

Curve (*c*), which is still linear but does not pass through the origin, represents the ideal stress-strain diagram for purely plastic flow first postulated by Bingham. If stress is less than some critical figure, So, no flow occurs, but if $S > So$ the difference between them produces plastic flow. Such behaviour can be represented by the equation, originally due to Bingham [2]

$$\frac{dv}{dy} = \frac{(S - So)}{\eta}$$

Experimental curves of the type shown in Fig 1 (b) can often be expressed by the Ostwald [3]—de Waele [4] equation

$$\frac{dv}{dy} = \frac{S^n}{\eta^*}$$

and those in Fig 1 (d) by the Herschel-Bulkley [5] equation,

$$\frac{dv}{dy} = \frac{(S - So)^n}{\eta^*}$$

Over a restricted range the Bingham and Ostwald-de Waele (or Herschel-Bulkley) relations might apply with equal accuracy. On the other hand, some liquids may exhibit quasi-plastic (or quasi-viscous) flow at low stress while obeying Bingham's law at higher stresses (shown as dotted lines in Fig. 1); such materials are, in fact, quite common. Curves (*a*) and (*b*) strictly speaking refer to fluids and (*c*) and (*d*) to solids since $So = o$ and $So > o$ in the two cases. We write η^* in place of η since in these equations it no longer has the dimensions of a viscosity and cannot be expressed in poises. Since the formation of a structure in many colloids causes viscosity to vary with stress, Ostwald uses the term "structural viscosity" (strukturviskosität) to describe η^*. He also postulates a type of structural turbulence which differs from that occurring in Newtonian liquids.

It is possible of course that the proportionality between $\frac{dv}{dy}$ and S observed with pure liquids may be nothing more than a limiting law for low stresses, so that divergence might occur at stresses which cannot be obtained in practice. On the other hand de Weale [6] suggests that all materials give Bingham curves if sufficiently high stresses are employed.

Laminar Flow.

A graphical representation of possible deviations from Newtonian behaviour has been given. Turning now to the question of the laminar flow of elastic fluids, it must be admitted

that no rigid theory exists, all are semi-empirical. The first " theory " to be considered is one that has already been referred to, namely that in which a law of the type,

$$\frac{dv}{dy} = \frac{(S - So)}{\eta}$$

is postulated. With $S < So$ energy is used in overcoming internal elastic stresses in the material and there is no flow. With $S > So$ the liquid flows as a normal liquid of viscosity η (constant) and obeys Bingham's law. *So* is introduced here as the rigidity.

Controversy exists over the existence of *So* and there is reason to believe that there is always some flow which may be less than the sensitivity of the apparatus can record. However, the formula can be used to represent a large amount of experimental data with fair accuracy. We might digress for a moment here in order to see what happens when Bingham's equation is applied to capillary flow. Taking these conditions into account Buckingham [7] and Reiner [8] have independently obtained a modified Poiseuille equation for mobility.

$$\frac{1}{\mu} = \frac{\pi R}{8LV}\left(P - \frac{4}{3p} + \frac{p4}{3p^{3}}\right)$$

where p is the pressure corresponding to *So* i.e. $So = pR/2L$. If $P \gg p$ the last term can be neglected and this becomes, since $S = PR/2L$

$$\frac{1}{\mu} = \frac{\pi R^{4}}{4v}\left(S - \frac{4}{3}So\right)$$

The curve is of the general form of the Bingham type, but the extrapolated intercept is $4/3.So$, *So* being the true intercept. Part of the curvature encountered with so many materials is thus accounted for.

The next " theory " does not assume a yield value *So*. Newton's law is considered to be valid with the extension that η is not constant but is a function of *S*. Three assumptions are made:

(i) at low stresses, the flow curve is straight indicating a viscosity η^{0}

(ii) at the highest stresses, the curve is again straight with viscosity η^{∞}

(iii) the transition from η^{0} to η^{∞} must occur when *S* is of the order of a characteristic quantity *So*, identified as the rigidity.

The simplest equation which satisfies these assumptions is

$$\eta = \eta^{\infty} + \frac{\eta^{0} - \eta^{\infty}}{1 + (S/So)^{2}}$$

$(S/So)^2$ occurs since the direction of flow cannot affect the viscosity. This relation was first obtained by Reiner [8]. As with the Bingham treatment it is necessary to see how the Poiseuille formula is altered in studying capillary flow. Philippoff [9] has modified the equation to give an equivalent viscosity,

$$\eta_p = \eta^{\infty} + \frac{\eta^0 - \eta^{\infty}}{1 + 2/3(S/So)^2}$$

The characteristic constants of the material η^0 η^{∞} and So can be found from this. If the Couette type of instrument is used we get a similar expression for η^0 but with a constant differing from 2/3.

Measurements by Hatschek and others have been examined by Philippoff and fitted to this type of equation. Characteristic constants obtained in this way for a number of materials are given in the following table.

	η^0	η^{∞}	So	τ^0 sec.
45% Gum arabic sol—30°C	2.7	0.40	0.09	3.0
Sulphur melt—120°C ...	0.21	0.010	0.07	3.0
Cholesterin butyrate—100°C	2.4	0.35	1.0	2.3
Hexane 70% methanol 30%	0.03	0.003	0.05	0.7
Polystyrene 0.4% in tetrolin	4.0	1.0	500	0.008
Viscose 4%	4.4	2.2	970	0.004

η^0 η^{∞} So in CGS units. (After Philippoff).

Some of the curves investigated by Philippoff, for example, Reiner's results on rubber solutions using Couette and capillary viscometers and Ostwald's experiments on amyl-acetate, could not be accounted for by such an equation and he suggests that these could be better represented by a power law.

As Gemant remarks [10] several general theories have been put forward to account for the phenomenon of structural viscosity; one might mention those of Henky [11] and Weissenberg [12], but so far these have not proved very helpful. We will however, refer to Weissenberg's theory later.

Relaxation Processes.

Referring to the time constant in the Table it is clear that an elastic fluid can maintain a static strain since it possesses both elasticity and viscosity. In other words if a stress is suddenly applied, deformation takes place, and if it is maintained then the stress will decrease with time finally reaching zero. This phenomenon is known as relaxation.

A rigid relaxation theory is missing but we will consider briefly Maxwell's simple law [13]. Suppose a material is

deformed in such a manner that part is recoverable (elastic) and part non-recoverable (viscous). Then if σ is a strain

$$\text{Stress } S = So\,\sigma$$

where So is the rigidity modulus (for a shear). Hooke's law is independent of time, so that

$$\frac{dS}{dt} = So\,\frac{d\sigma}{dt}$$

If the body is partly viscous, stress will fall and Maxwell assumed that the rate of fall was proportional to stress, and then

$$\frac{dS}{dt} = So\,\frac{d\sigma}{dt} - \frac{S}{\tau_0}$$

where τ_0 is a constant. If deformation is considered constant ($d\sigma/dt = o$) then $\tau_0 = S/\frac{dS}{dt}$ and the stress after a time t, is

$$S = So\,\sigma e^{-t/\tau_0}$$

τ_0 is the time for the stress to fall to $1/e$ of its original value and not the time for it to reach zero.

If σ varies it is interesting to see what happens when $d\sigma/dt$ is constant (steady motion which continually increases the displacement). The original equation leads to

$$S = So\,\tau_0\,\frac{d\sigma}{dt} + \text{const. } e^{-t/\tau_0}$$

showing that S tends to a constant value depending on rate of displacement. Quoting Maxwell: "The quantity So by which the rate of displacement must be multiplied to get force, may be called the coefficient of viscosity. It is the product of the coefficient of elasticity So and a time τ_0 which may be called 'time of relaxation' of the elastic force. In mobile fluids τ_0 is a very small fraction a second and So is not easily determined experimentally. In viscous solids τ_0 may be several hours or days, and then So is easily measured. It is possible that in some bodies τ_0 may be a function of S."

In other words $\eta_0 = So\,\tau_0$ if Maxwell's assumptions are true. Schwedoff [14] first tested Maxwell's law using gelatine. Referring again to the cylinder suspended in a cylindrical cup containing a liquid, if we twist the upper end of the suspension wire through an angle θ, then for a true liquid the cylinder would also move through an angle θ. If the liquid possesses rigidity it moves through a smaller angle ω. Then the torque is $\beta(\theta - \omega)$ where β is the torsional moment per unit angle. The rigidity So is then given by

$$So = \frac{\beta}{4\pi b}\left(\frac{1}{a^2} - \frac{1}{b^2}\right)\frac{\theta - \omega}{\omega}$$

h is the effective height of liquid, and a and b are the radii of the cylinders. This idea has been used to measure shear modulus of liquids.

When the material is not perfectly elastic, any elastic strain is gradually dissipated. If then the torque is gradually reduced, keeping the deflection constant, values of $(\theta - \omega)$ should give a log. curve when plotted against time if Maxwell's law is true. Actually Schwedoff and also Hatschek and Jane [15] using 0.3% benzo. purpurin found that this did not hold in practice. The fluid apparently maintains a small residual deformation permanently, the magnitude of which is very uncertain. Schwedoff proposed for gelatine.

$$\delta_t = a(1 + be^{-\alpha t})$$

in which δ_t is the torsion in the wire at time t, and a, b, and α are constants. a is the residual deformation when $t = \infty$. Hatschek and Jane's results however, did not agree either with Maxwell's or Schwedoff's equation. Trouton and Andrews [16] with pitch and Schofield and Scott-Blair [17] with dough have also obtained relaxation curves which are not logarithmic.

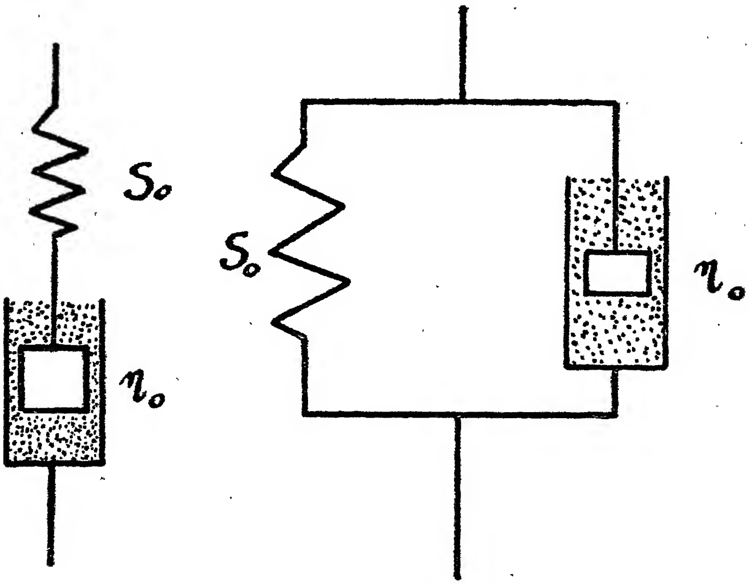


FIG. 2.

Maxwell's law is sometimes illustrated by a model [Fig. 2(a)] comprising a piston and spring in series. In the viscous part (piston) resistance is proportional to rate of displacement while in the elastic part (spring) it is proportional to the displacement.

Vibrational Processes.

If the process is a vibrational one, it tends to assume the character of an elastic displacement, since there is no time for flow to develop. The viscous motion will change to elastic when the period of vibration becomes of the order of τ_0. A dynamic viscosity η' is therefore introduced, usually represented by a parallel connection of viscous and elastic elements [Fig. 2(b)]. It can be shown that with such a system

$$\eta' = \eta_0 / [1 + (\omega\tau_0)^2]$$

Philippoff ([18]) carried out experiments in order to verify this relation using a metal rod dipping into the liquid and maintained in vibration with a valve circuit. By measuring anode current and the amplitude and frequency of vibration, Philippoff was able to calculate values of η_0, S_0 and τ_0 but he found that the best agreement was obtained when $(\omega \tau_0)^{3/4}$ was substituted for $(\omega \tau_0)^2$ in the above equation. Figures for τ_0 so found agreed well with values obtained from stationary flow measurements.

This then was the position at the beginning of the war, when the three characteristics of an elastic fluid were known to be

(i) non-linearity between stress and rate of shear,

(ii) finite relaxation process for suddenly applied stresses,

(iii) frequency dependent dynamic viscosity for alternating processes.

Further Flow Anomalies.

At about this time the author was carrying out experiments on elastic fluids using a capillary viscometer (of the type used by Arveson) and certain rather curious effects were discovered ([19]). It was found that the non-linearity between stress and rate of shear occurred but, in addition, the relationship depended on the length and diameter of the capillary which was very marked in some instances. It was found also that these "flow" curves could be made coincident if plotted with a parameter of L/D (irrespective of the actual values of L or D), forming a family of curves. These showed that if L/D is sufficiently large, the curves approximate to a line independent of tube bore. Smaller L/D ratios diverge from this indicating a relatively lower rate of flow.

This effect, in which longer capillaries indicate lower apparent viscosities than short ones, was observed as long ago as 1931 by Peek and Ericson ([20]) with a rubber solution, but they did not attempt any correlation of their results.

Now it is well known that when a Newtonian liquid enters a tube, equilibrium is not immediately established, accelerations occurring before the final velocity distribution is reached. This will also occur with non-Newtonian liquids, and, in addition, with elastic fluids it was postulated that the material is "stretched" or elastically deformed—in the most general sense of the word—until equilibrium is established for the particular stress applied, the liquid flowing through the remainder of the tube in this state. For very long tubes this "elastic end effect" would tend to become negligible in comparison with the overall length and flow curves would then give a true, or nearly true, representation of the behaviour of the material under the particular conditions. As tube length decreases the end effect becomes large in proportion to the total length and we should expect a progressive departure from the "limiting" curve.

To verify that this is due to an end effect and not to any gradual change in viscosity, (i.e. thixotropy) at any given rate of shear, values of $PR/2L$ (stress) plotted against D/L should result in a linear relation, the intercept giving a point on the limiting curve ($L=\infty$). In other words all L/D ratios can be made to coincide by applying a single end correction, different for each rate of shear. This has been verified in all experiments done so far, some by independent observers in this country and in the U.S.A. (unpublished). If the effect were due to thixotropy then these curves would not in general be linear.

This divergence in the flow curves found to be independent of R, and traced to an entrance effect was therefore attributed in a general way to the elastic nature of the material since it was known not to occur with Newtonian liquids or solid-liquid suspensions. We should also expect this end effect to increase with stress and this would accentuate the difference in the flow curves. The results clearly illustrate this point.

This correction may be plotted in an empirical manner. The fall in pressure per unit length, P/L, is greater than the equilibrium figure and a quantity $k.D$ is added to L to allow for it. This is analagous to the Couette correction applied for the same reason; the value of k for Newtonian liquids is about 0.8; here the value of k is obtained from the slope of the curves just referred to. A plot of k against stress shows the expected increase with increasing stress. Furthermore, the curves extrapolated to about 0.8 D at the point where the "flow" curves deviate from Newtonian behaviour.

It was postulated that the material is suffering from elastic deformation during flow, and this can readily be demonstrated by suddenly releasing the pressure tending to force the liquid through the capillary; a small speck of dust in the liquid shows recoil. This is sometimes referred to as flow-elasticity.

When the material emerges from the tube it tends to return to its "unstretched" condition and this gives rises to a swelling of the issuing column which is easily observed. The phenomenon of elastic recovery is well known and has been studied by Dillon and Johnstone for solid rubber, who found that recovery increased with increasing flow. Recovery was measured in terms of the area of cross section of the extruded segment, and plotted as a function of V. Here the ratio of the area of the extruded segment to that of the capillary, plotted against shearing stress shows a linear relationship independent of *R;* recovery also decreases with increasing %.

At high stresses corresponding to velocities of 1 or 2 m/sec., recovery is delayed, the delay increasing with stress ([21]). All the materials and concentrations so far studied show this phenomenon. It was also found that with certain solutions the onset of the delay, coincides with an unmistakeable "kink" in the flow curve, indicating a sudden increase in flow rate. It is not possible at this stage to state the exact cause of these anomalies—the delay in recovery and sudden increase in flow rate—but several explanations are possible. The most likely explanation involves the question of time. At low velocities recovery is very rapid compared with the downward movement, but at high velocities the liquid may not be able to make any appreciable recovery until it has moved some distance from the tube; hence the delay in the swelling.

With normal recovery the swelling is usually very rapid and it seems possible that this may react on flow immediately inside the tube, producing a small "back-pressure" tending to restrict the flow. This restriction would be removed when recovery took place well away from the tube and we might expect a sudden increase in flow rate at the transition. This idea seems to be supported by the fact that the "kink" is apparent in precisely those materials which show a relatively large recovery.

WEISSENBERG'S EXPERIMENTS.

Finally, I should like to refer briefly to some experiments carried out at about the same time by Weissenberg and co-workers (unpublished)*. These are perhaps the most important of any of those referred to in this lecture. Firstly he has measured the rigidity of some elastic fluids by an oscillation method using a cylinder vibrating in a horizontal plane about a vertical axis. Shear vibrations are propagated radially from the circumference of the cylinder into the liquid. For true liquids we get the appearance shown in Fig. 3(a) with the amplitude increasing radially. (The wave form is observed by painting a

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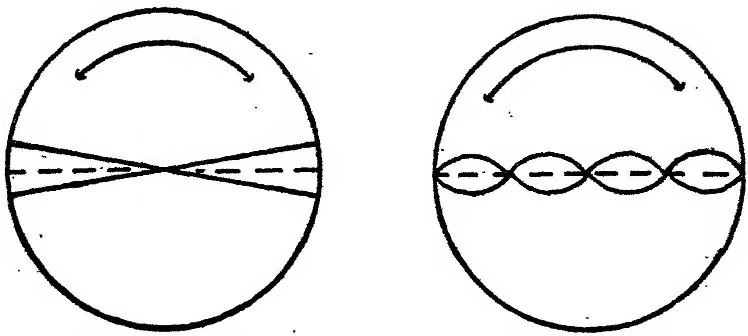
* c.f. British Pheologists' Club Conference, Bedford College, London, October, 1946; Nature, 1947, issue 159, p. 150.

line on the surface through the centre with aluminium powder suspended in a solvent.) For a perfectly elastic liquid standing waves would be set up by interference with waves propogated from opposite sides of the cylinder [Fig. 3(b)]. The bottom of the cylinder exerted a distorting influence on the wave form but this was eliminated by floating the liquid on a medium of low viscosity but of higher density.



(*a*) Purely viscous. (*b*) Purely elastic.

FIG. 3 (after Weissenberg).

In this type of experiment in which shearing waves are propogated into the bulk of the liquid, the elasticity modulus is not determined explicitly even for a perfectly elastic body. What is determined is the velocity of propagation of the shearing wave, and this is related to shear modulus *So* by

$$v = \sqrt{So/\rho}$$

from which *So* can be determined (ρ being the density).

When a fluid is visco-elastic, Weissenberg has shown that if there are points of minimum amplitude, the error in assuming the material to be perfectly elastic is very small. Viscosity effects become greater at large radii, while the central portion is mainly influenced by elasticity. This is confirmed by experiment and it was found that the modulus was substantially independent of frequency (2-50 c/sec). Values found in this way were of the order of 10^3 dynes/cm^2, compared with 10^6-10^8 for rubber and 10^{12} for steel.

Richardson ([22]) has separated the elastic and viscous factors for such a liquid in a similar apparatus, using hot-wire methods of amplitude measurement.

Finally we come to an experiment which, although simple in nature, is likely to have profound repercussions. Suppose we

support a circular metal disc in a rotating cylinder containing the fluid (Fig. 4). Rotation of the disc is prevented but it is free to move vertically. With a Newtonian liquid the disc remains stationary tending only to rotate but with an elastic fluid it is found that the disc is pushed up to the surface of the liquid, obviously due to a thrust normal to the plane of shear. Measurement of this pressure was made by balancing with weights. There is no normal pressure however if the cylinder is oscillating.

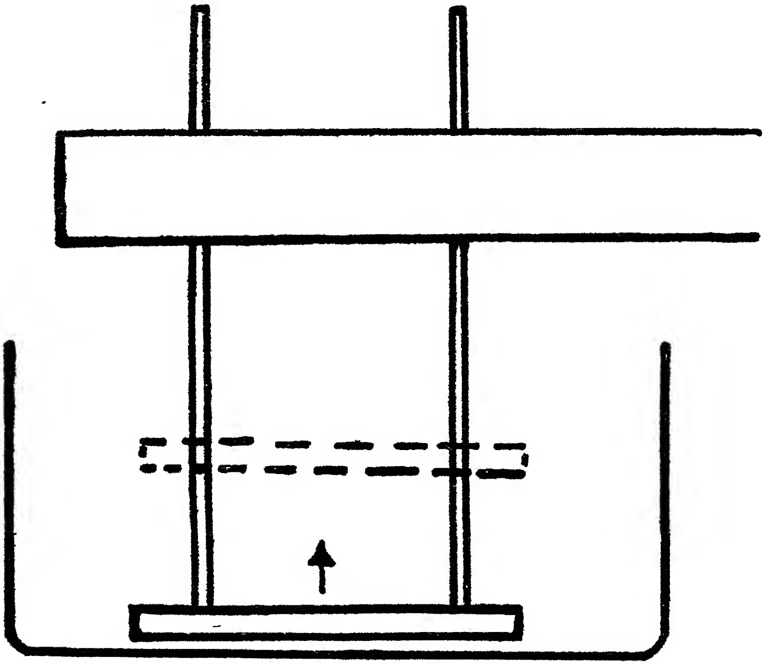


FIG. 4 (After Weisserberg).

This phenomenon, predicted by Weissenberg, is accounted for in the following manner. Now in vibration experiments with non-Newtonian fluids, and with small amplitudes of vibration, stress and strain tensors should be parallel as in Newtonian liquids and it should be possible to calculate the true constants for the fluid under investigation which would be quite independent of the stresses and strains involved.

For laminar flow with large displacements, these conclusions no longer apply, since stress and strain velocities are no longer parallel, the angle between them increasing with increasing

velocity. Thus the anomalous flow of such liquids shown by a decrease in the ratio shear stress/rate of shear, as the rate of flow is increased, *is due to the change in this angle* and not to any change in the real viscosity or other mechanical property of the fluid. Quantitative measurements confirm this amazing prediction, that stress/rate of shear is constant. The divergence between stress and strain velocities also results in the appearance of a force normal to the boundaries of the fluid; it is this component which causes a column of liquid to expand when emerging from a capillary.

To sum up—the behaviour of elastic fluids is very complex and up to the present no rigorous theory exists, although the recent work of Weissenberg undoubtedly represents a very great step forward.

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CONTENTS

The Vascular Plants of Stuley Island, The Isles of Grimsay and Ronay, with Some Remarks on the Flora of Benbecula, South Uist and Barra

By

J. W. HESLOP HARRISON, D.Sc., F.R.S. and
JOHN HESLOP HARRISON, M.Sc.

When our investigations into the Flora of the Inner and Outer Hebrides commenced in 1934, the work was undertaken with the intention of producing a comprehensive flora of both groups of islands. However, as the investigations proceeded, it became quite obvious that our aims had to be extended so as to cover the biogeography of the area as well as certain aspects of its ecology.

To the senior author of this paper, because of his acquaintance with the zoology of the islands, has fallen the main task of tackling the broader problems presented by their flora and fauna; in particular, utilizing all the known, pertinent biological facts, he has endeavoured to determine the history and origin of Hebridean plants and animals, and also to fix dates for the last and the penultimate severances of the Hebrides from the mainland and from one another.

In connection with the ecology, one of us, (J.H.H.) has already made considerable progress in his analysis of the plant communities, characterizing the so-called machair, often strongly developed along the western shores of the Outer Isles, and, occasionally, in the Isles of Coll and Tiree. In addition, he has initiated intensive studies in the orchid populations of the Hebrides, dealing with them from the systematical, genetical and phytogeographical standpoints.

The furtherance of this programme rendered it necessary that Coll, Tiree, Benbecula, South Uist and Barra should be subjected to more intensive and critical examination. Moreover, it became desirable for us to complete our studies on Baleshare, and to visit Stuley Island, and the Isles of Grimsay and Ronay. Of these Stuley Island was explored in 1946, and Baleshare, Grimsay and Ronay in the course of our stay on Benbecula.

Geologically speaking, in general, there appears to be little to differentiate the various members of the Outer Group. Nevertheless, Stuley Island, lying to the east of South Uist and just south of Loch Eynort, except for a small exposure of Green Mashed Gneiss toward the north east, is recognized at once as peculiar

by the flaggy nature of the mylonites of which it is built. Baleshare, just west of North Uist, for the most part low, sandy and sterile in nature in the south, shows a gradual passage to more fertile machair and machair-moorland transition areas in the north. The Isle of Grimsay, situated between North Uist and Benbecula, appearing at first sight a low, desolate forbidding island, nevertheless possesses a surprisingly large amount of usable land and an array of rather picturesque lochs; it differs but little in general structure from its larger neighbours. On the other hand, Ronay, in conformity with its name, rises as a rugged rocky mass to the east of Grimsay, although in the north west, facing Grimsay, it displays a small area of productive soil. Its geology is interesting, inasmuch as the island forms part of the belt of flinty crush rock stretching down the east side of the "Long" Island from Lewis to Barra.

In setting forth the fruits of our more recent work, for the sake of completeness, certain records resulting from earlier King's College Biological Expeditions to the Hebrides are included.

Our thanks are due in the first place to King's College Research Committee for their generous support and to Miss M. H. Oates who rendered valuable assistance in the general work of the expedition.

Except that capitals are inserted in accordance with accepted botanical nomenclature, and in the case of the Potamogetons, the names employed are those of the "Check List of British Vascular Plants" issued by the British Ecological Society.

Thalictrum arenarium Butcher.
On the dunes and machair, Baleshare.

Ranunculus trichophyllus Chaix.
In various lochans on Baleshare, and Loch Dun Mhurchaidh, Benbecula.*

R. Baudotii Godr.
In the form of var. *marinus* Fr. in Loch Ardvule, South Uist.

R. sceleratus L.
In ditches on the machair near Bornish, S. Uist and on Baleshare.

R. Flammula L.
Around lochans and runnels, Isles of Ronay and Grimsay and Stuley Island.

R. acris L.
Common on Baleshare, Ronay, Grimsay, but rare on Stuley Island.

R. repens L.
As with the preceding species.

R. bulbosus L.
Rather rare on Baleshare.

Caltha palustris L.
Not uncommon on Baleshare; rather rare on Stuley Island.

C. radicans Forst.
Only on Baleshare near Loch Mhor.

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* Records for the Isles of Barra, South Uist and Benbecula are only supplied when the plants concerned are new to v.-c. 110, or when new stations or interesting facts about important plants are given.

Nymphaea alba L.
In some of the lochs like Loch na Leig, Ronay and Lochs Fada and Caravat, Grimsay.

N. occidentalis Moss.
On both Grimsay and Ronay, but less plentiful than the preceding.

Papaver dubium L.
Rare in fields, Baleshare.

Fumaria Bastardii Bor.
Sporadic in corn on Benbecula and Baleshare.

Nasturtium officinale R. Br.
In view of the separation of *N. uniseriatum* Howard & Manton, it seems necessary to point out that this form exists on machair streams on Benbecula, South Uist and Baleshare, as well as at Kyles Stuley and Arinambane in the east of S. Uist.

N. uniseriatum Howard & Manton.
Only in the road side ditch leading from Bornish Post Office to the machair, S. Uist. As a sterile form also occurs, it is almost certainly the hybrid between this and the preceding species.

Cardamine pratensis L.
Common on Baleshare, Ronay and Grimsay; the var. *dentata* Schult. is now reported from Loch Eynort, S. Uist.

C. hirsuta L.
Not uncommon, Baleshare, Ronay and Grimsay; now recorded from Borve, Barra, for the first time.

C. flexuosa With.
Sparingly, Stuley Island, Baleshare, Ronay and Grimsay.

Erophila praecox (Stev.) DC.
On dune and machair, Baleshare.

Cochlearia officinalis L.
East shores of Ronay and Baleshare; also near Lidistrome, Benbecula.

C. alpina Wats.
On Feaveallach, S. Uist, an additional station.

C. scotica Dr.
On the coasts of Stuley Island, Grimsay and Ronay, fairly common.

Arabidopsis Thaliana (L.) Heynh.
Collected in Hellisdale, S. Uist, the first locality known for the species in v.-c. 110.

Sinapis arvensis L.
On cultivated land, Baleshare and Grimsay.

Capsella Bursa-pastoris (L.) Medic.
Irregularly and thinly distributed on Grimsay and Baleshare.

Lepidium ruderale L.
On waste ground, Lochboisdale, S. Uist; first record for v.-c. 110.

Cakile maritima Scop.
On the coast of Baleshare.

Raphanus Raphanistrum L.
The form *aureus* Wilm., in oats on Grimsay.

Viola palustris L.
Scattered in damp moorland hollows on Baleshare, Grimsay and Ronay.

V. Riviniana Reichb.
Quite common on Stuley Island, Baleshare, Grimsay and Ronay.

V. Lloydii Bor.
Amongst grass near Loch Mhor, Baleshare.

V. Curtisii E. Forst.
On the dunes and machair, Baleshare.

Polygala vulgaris L.
Only on the machair and amongst the dunes, Baleshare.
P. oxyptera Reich.
On all the islands but not well distributed.
P. serpyllifolia Hose.
Only noted with certainty on the hills of Ronay and on Stuley Island.
Silene maritima (Hornem.) With.
In huge masses along the south east shores of Baleshare, both on dunes and shingle.
Melandrium album (Mill.) Garcke.
South of Nunton, Benebecula; seeds unusually large.
M. dioicum (L.) Coss. & Germ.
A further station on S. Uist in Hellisdale is now noted; in this locality a plant with five free carpels was noted. As the observation is one of great phytogeographical significance, it should be emphasized that the plant occurring on the Isles of Rhum, Tiree, South Uist and Muldoanich belongs to var. *zetlandica* Compt.
Cerastium semidecandrum L.
Only observed on the machair, Baleshare.
C. viscosum L.
On Baleshare and Grimsay.
C. vulgatum L.
On Stuley Island, Baleshare, Grimsay and Ronay.
C. Edmondstonii (Edmons.) Murb. & Ostenf.
A search for this species in August 1947 on Rueval, Benbecula, where it was obtained in 1942, proved fruitless; even the *Rosa canina* var. *lutetiana* growing with it had been burnt off.
Stellaria media (L.) Vill.
On Baleshare, Ronay, Grimsay and Stuley Island.
S. uliginosa Murr.
On Grimsay and Stuley Island.
Arenaria serpyllifolia L.
Plentiful on dune and machair, Baleshare.
A. peploides L.
A form previously missed on Baleshare, but common on the shore and even on the machair.
Sagina maritima Sm.
Sparingly on Grimsay and Ronay on rocks.
S. procumbens L.
On Stuley Island, Baleshare, Grimsay and Ronay.
Sagina nodosa (L.) Fenzl.
Now recorded from Baleshare from damp flats in the dunes.
Montia fontana L.
Everywhere on Grimsay and Ronay, but rarer on Baleshare and Stuley Island.
Elatine hexandra DC.
Obtained in Loch Kildonan, S. Uist and Loch Dun Mhurchaidh, Benbecula, still further closing the gap between its Harris and Barra stations.
Hypericum pulchrum L.
Widely spread on moorland slopes and cliffs on Stuley Island, Grimsay and Ronay; on Baleshare, rare in the north. The var. *procumbens* also occurs.
H. elodes L.
More widely distributed on South Uist than formerly thought, for now it has been collected in many places near Lower Loch Ollay, Loch an Tuirc and to the west of Loch Ceann a' Bagh; also in plenty around and in lochans on Baleshare.

Radiola Linoides Roth.
Very abundant on a path near one of the lochans on Grimsay; also to the west of Rueval, a new station on Benbecula.

Linum catharticum L.
Common in dry places on Ronay and Grimsay and, in spite of our having recorded as absent on Baleshare, plentiful on dune and machair there.

Geranium pratense L.
On the machair near Bornish, S. Uist; perhaps an escape, but new to v.-c. 110.

G. molle L.
On the machair, Baleshare.

Erodium cicutarium L. 'Herit.
On dunes and in disused potato-patches on Baleshare.

Oxalis Acetosella L.
On the Isle of Ronay when it occurred at the base of every inland cliff and amongst bracken; also noted on Stuley Island, again amongst bracken.

Medicago lupulina L.
On the machair near Balevanish, Benbecula.

Trifolium pratense L.
Found on Baleshare.

T. repens L.
Occurs on Stuley Island, Baleshare and Grimsay often abundantly.

T. campestre Schreb.
On the aerodrome, Balevanish, Benbecula; new to v.-c. 110.

Anthyllis Vulneraria L.
Quite common on Baleshare, where the var. *villosa* Corb. also grows.

Lotus corniculatus L.
Locally common on Stuley Island, Baleshare, Grimsay and Ronay.

Vicia Cracca L.
Very rare on Grimsay; scattered on Baleshare.

V. sylvatica L.
In Hellisdale, S. Uist.

Filipendula Ulmaria (L.) Maxim.
Specially noted in our Flora of the Outer Hebrides as absent from Benbecula, now reported as common around Loch Dun Mhurchaidh, on islets in that loch and in other places in the Uachdar area, Benbecula; also on Ronay near Buaile Mhor; sparingley on Stuley Island and in magnificent clumps, Kyles Stuley, S. Uist.

Rubus polyanthemus Lindeb.
In cliffs and along streams, Ronay.

R. ulmifolius Schott.
In the Allt Volagir ravine, Loch Eynort, S. Uist.

R. mucronifer Sudre.
Common around Loch na Leig and other lochs on Ronay.

R. gratus Focke
Here and there on Ronay.

Potentilla erecta (L.) Hampe.
Common on the moorlands of all the islands.

P. Anserina L.
In waste places and along the shores, Baleshare, Ronay, Grimsay and Stuley Island.

P. palustris L.
In ditches and around lochs, Baleshare, Grimsay and Ronay.

Alchemilla arvensis L.
Rare on Baleshare.

A. filicaulis Buser.
Rare near Lochboisdale, S. Uist.

Agrimonia odorata (Gouan) Mill.
Not rare as formerly stated, but very abundant near Kyles Stuley, S. Uist.

Rosa Sherardi Dav.
In the form of vars. *omissa*, *suberecta* and *Cookei* on the Isle of Ronay.

Sorbus Aucuparia L.
Scattered here and there on rocky loch edges on the Isle of Ronay but rarer on Grimsay. Mention should be made of a very well grown tree on a sea cliff near Minish, Benbecula, bearing two buzzard's nests.

Saxifraga oppositfolia L.
Found also on Feaveallach in the Beinn Mhor group of mountains, S. Uist.

S. aizoides L.
In a wet gully at about 950 feet, N.W. exposure, between Hartaval and Heaval, Isle of Barra; dispersed over about 60 sq. yds First record for v.-c. 110.

S. platypetala Sm.
This species was detected for the first time for the Outer Isles (v.-c. 110) on Beinn Mhor. As it was a very unusual form, we grew it on and discovered that it varied enormously under cultivation. We recorded it as *S. decipiens* Ehrh. as our specimens agreed best with figures and descriptions of that plant. We place it under its present name because we think that many of the alleged new species described amongst its close allies are only growth forms. Wilmott's record was, of course, not the first for v.-c. 110; his introduction of a fresh name for a plant he had previously named *S. hirta* Sm. was new!

S. hypnoides L.
A true *hypnoides* form also grows on the Beinn Mhor massif; in this again we provided the first record for v.-c. 110.

S. tridactylites L.
Common on dune and machair in Baleshare in April and May.

Chrysosplenium oppositifolium L.
A new locality for this rare Outer Island plant is Eilean Eallan, Loch Eynort, S. Uist.

Sedum roseum (L.) Scop.
On the east coast cliffs of the Isle of Ronay.

S. anglicum Huds.
Abounds in rocky places, sometimes well inland, on Baleshare, Grimsay, Ronay and Stuley Island.

S. acre L.
On the Baleshare dunes.

Drosera rotundifolia L.
Common on Ronay and Grimsay; rare on Stuley Island.

D. anglica Huds.
On the same islands but less common.

D. longifolia L.
Surprisingly well distributed in north-east central Benbecula.

Hippuris vulgaris L.
Around the lochans, Baleshare; not recorded by us from the Isle of Barra, but now known from a marsh at Saltinish, and west of Eoligarry boat harbour on the island.

Myriophyllum spicatum L.
In the lochs, Baleshare, Grimsay, Ronay.

M. alterniflorum DC.
Found in lochans on Grimsay and Baleshare.

Callitriche stagnalis L.
Not rare on Grimsay and Baleshare.

Peplis Portula L.
In a lochan west of Loch Caravat, Grimsay.

Epilobium hirsutum L.
A single plant in a marsh north of Lochboisdale, S. Uist; first record for v.-c. 110.

E. parviflorum L.
Not common, Stuley Island, Baleshare, Ronay and Grimsay in marshes.

E. obscurum Schreb.
Common on all the islands.

E. palustre L.
As with the preceding.

Hydrocotyle vulgaris L.
Common in suitable places on Grimsay and Ronay, but rarer on Baleshare and Stuley Island.

Apium inundatum (L.) Rchb. f.
In lochans on Baleshare.

Anthriscus sylvestris (L.) Hoffm.
Very rare on Ronay.

Myrrhis Odorata (L.) Scop.
On the machair edge, Bornish; like all Outer Island occurrences of the species, possibly an introduction.

Oenanthe Lachenalii C. Gmel.
Common around lochans on Baleshare.

Oe. crocata L.
Rather common around a lochan east of the Creag Mhor, Ronay, also near the landing place, Stuley Island; on South Uist, additional localities are South Boisdale to Kilbride, mouth of Allt Volagir, Loch Eynort.

Ligusticum scoticum L.
In our Preliminary Flora we were unable to include this plant from North Uist; it, however, abounds on cliffs in the east of Ronay.

Angelica sylvestris L.
Common on Baleshare, Grimsay, Ronay and Stuley Island; also on islets in the lochs.

Daucus Carota L.
Fairly common on the machair, Baleshare.

Lonicera Periclymenum L.
Quite common on cliffs and rocky loch edges on Ronay; much rarer on Grimsay, always as var. *Clarkii* Heslop-Harrison.

Galium verum L.
Rather common on the machair, Baleshare.

G. palustre L.
In one or two stations in the north of Ronay and on Grimsay; commoner on Baleshare.

G. saxatile L.
Not all common: Stuley Island, Baleshare, Grimsay and Ronay.

G. Aparine L.
On shingle rare on Stuley Island; not rare on Baleshare.

Valerianella locusta L.
Occasionally on the machair on Baleshare and Benbecula.

Succisa pratensis Moench.
Rarely in the north of Baleshare, common on Stuley Island, Grimsay and Ronay.

Solidago Virgaurea L.
On cliffs etc. on Ronay, Grimsay and Baleshare; as on Benbecula, most of the forms would be regarded as appertaining to var. *cambrica* Huds.
Bellis perennis L.
Common on all the islands.
Aster Tripolium L.
Not rare in the east of Baleshare; the form *arcticus* Th. Fr. prevailed.
Antennaria dioica L.
Rare and local on Baleshare, Grimsay and Ronay; its occurrence on Baleshare seems noteworthy.
Gnaphalium uliginosum L.
Rare on Grimsay only.
Inula Helenium L.
Near crofts, Eoligarry, Isle of Barra.
Achillea Millefolium L.
Common on Baleshare, Grimsay and Ronay; less so on Stuley Island.
Anthemis Cotula L.
South of Nunton, Benbecula.
Chrysanthemum segetum L.
In oatfields, Baleshare and Grimsay.
C. Leucanthemum L.
On Baleshare, between Loch Mhor and school loch; on the Isle of Barra near Tangusdale and Borve.
Matricaria maritima L.
Plentiful on the eastern cliffs of Ronay; rare on Stuley Island.
M. inodora L.
On Grimsay and Baleshare.
M. suaveolens (Pursh.) Buch.
Everywhere in waste places on Baleshare, and Grimsay; rare near deserted croft, Bhuaile Mhor, Ronay.
Tanacetum vulgare L.
Very rare on Ronay near old buildings in the north; also on Grimsay and Baleshare.
Artemisia vulgaris L.
Baleshare and Grimsay.
Senecio vulgaris L.
Not rare on all the islands.
S. Jacobaea L.
Only on low grassy cliffs in the north west of Ronay, on grassy slopes, Grimsay; plentiful on the machair and elsewhere, Baleshare.
S. aquaticus Hill.
One or two plants near the landing place, Stuley Island, here and there on Baleshare.
Arctium vulgare (Hill) A. H. Evans.
On Baleshare, Ronay and Grimsay but not common.
Cirsium vulgare (Savi) Ten.
Baleshare occasionally.
C. palustre (L.) Scop.
At many points on Baleshare, Grimsay and Ronay, not common; rare on Stuley Island.
C. arvense (L.) Scop.
On Baleshare and Grimsay.
Centaurea nemoralis Jord.
Thinly distributed in grassy places on Baleshare, Grimsay and Ronay; rare on Stuley Island.

Crepis capillaris (L.) Wall.
As with the preceding but a little more plentiful.
Hieracium uisticolum Pugsl.
On cliffs on Ronay.
H. caledonicum F.J.H.
Also on Ronay cliffs.
H. iricum Fr.
On Stuley Island.
H. hebridense Pugsl.
In a gorge leading to the sea, Bolum Bay, S. Uist.
H. Pilosella L.
Rather local on Baleshare.
Hypochoeris radicata L.
Common on Baleshare, Grimsay, Ronay; rare in the drier parts of Stuley Island.
Leontodon autumnale L.
Common on the whole of the islands.
Sonchus oleraceus L.
Well distributed on Baleshare, Grimsay and Ronay.
S. asper (L.) Hill.
As with the preceding species.
S. arvensis L.
Amongst oats etc. Baleshare and Grimsay.
Lobelia Dortmanna L.
In Loch na Leig and other lochs on Ronay, in Lochs Caravat, Fada etc., Grimsay.
Campanula rotundifolia L.
Not noted previously on Baleshare, but growing freely on little knolls on the dunes and machair in the south of the island; both type and var. *speciosa* More occur.
Vaccinium Myrtillus L.
Fairly common in the central areas of Ronay; very rare on Stuley Island.
Calluna vulgaris (L.) Hull.
Common on hills and moorlands on Grimsay, Ronay and Stuley Island; only in the north central areas of Baleshare.
Erica Tetralix L.
Rarer on damper moorlands of Grimsay, Ronay and Stuley Island.
E. cinerea L.
Even less common than the preceding on the same islands.
Armeria maritima Willd.
Common on Stuley Island, Grimsay and Ronay, but limited in Baleshare to east central areas.
Primula vulgaris L.
On Ronay on cliffs and sheltered grassy slopes; also on Stuley Island.
Lysimachia nemorum L.
Along a stream running into Bolum Bay, S. Uist.
Glaux maritima L.
On coasts, Baleshare, Grimsay, Ronay.
Anagallis tenella (L.) Murr.
Quite local on Grimsay in the same locality as *Radiola Linoides.*
Samolus Valerandi L.
As a component of the machair-marsh vegetation around Loch Hallan, S. Uist.
Centunculus minimus L.
Collected on Grimsay in the same locality as *Radiola Linoides.*
Gentiana campestris L.
Previously recorded as failing on Baleshare, now found to be plentiful, with white-coloured forms, on the machair there.

G. baltica Murb.
Also on the Baleshare machairs.

Centaurium umbellatum Gilib.
Locally plentiful on the Baleshare machair.

Menyanthes trifoliata L.
In Lochs Fada, Caravat etc., Grimsay; Loch na Leig, Ronay; rather rare on Baleshare.

Lycopsis arvensis L.
As a weed of cultivation, Baleshare and Grimsay.

Myosotis caespitosa Schultz.
Frequent on damp ground, Baleshare; rare on Grimsay and Ronay.

M. repens G. & D. Don.
Local on Ronay, Buaile Mhor.

M. versicolor Sm.
Common enough in dry places on Baleshare, Grimsay and Ronay; one or two plants on Stuley Island.

Veronica arvensis L.
As a weed on Grimsay.

V. officinalis L.
Very rare on a rocky slope near Loch na Leig, Ronay.

V. scutellata L.
In damp spots on Baleshare and along the shores of Lochs Torussay and Dun Mhurchaidh, Benbecula; in machair streams and marshes, Daliburgh, S. Uist.

V. aquatica Bernoh.
Near Loch Ard Vule, S. Uist; first record for v.-c. **110**.

Euphrasia micrantha Rcht.
On all the islands.

E. curta (Fr.) Wetts.
Found on Ronay and Grimsay.

E. occidentalis Wetts.
Only seen on Baleshare.

E. nemorosa Löhr.
On Baleshare and Ronay.

E. confusa Pugsl.
On all the islands.

E. condensata Jord.
On the north shore of Loch Eynort, S. Uist; apparently new to v.-c. 110 (H.W.P. det.).

Bartsia Odontites L.
In waste places, around deserted crofts, Baleshare, Grimsay, Ronay.

Pedicularis palustris L.

P. sylvatica L.
Both of these species are far from rare on all the islands.

Rhinanthus minor Ehrh.
Scattered on Stuley Island, Grimsay and Ronay.

R. stenophyllus Schur.
On Stuley Island; Ronay and Baleshare.

Utricularia minor L.
Somewhat local on Baleshare, Ronay and Grimsay; in beautiful flower on the latter island.

U. vulgaris L.
On the same islands.

U. intermedia Hayne.
Only on Baleshare, not common.

Pinguicula vulgaris L.
Common on Stuley Island, Ronay, Grimsay; locally plentiful on Baleshare.

P. lusitanica L.
Not at all rare on Ronay; very rare on Grimsay.
Mentha aquatica L.
Damp places on Baleshare.
Thymus pycnotrichus Uecht.
On Ronay, and Baleshare.
T. zetlandicus Ronn. & Dr.
On Baleshare, Ronay and Grimsay
T. Serpyllum L.
On all the islands.
Scutellaria minor Huds.
Along loch edges and amongst bracken and sphagnum, Ronay.
Prunella vulgaris L.
On all four islands.
Stachys palustris L.
Locally abundant on Baleshare and Grimsay.
Galeopsis Tetrahit L.
In corn, only too plentiful, Baleshare and Grimsay.
Lamium purpurem L.
On Baleshare and Grimsay.
L. molucellifolium Fr.
Only on Grimsay.
L. amplexicaule L.
Near Lochboisdale, S. Uist.
Ajuga pyramidalis L.
In ravines leading to Bolum Bay, S. Uist.
Plantago Coronopus L.
Common on all the islands.
P. maritima L.
As with the preceding.
P. lanceolata L.
Also generally distributed.
P. major L.
On Baleshare, Grimsay and Ronay.
Littorella uniflora (L.) Ascher.
Abundant in lochans on Ronay and Grimsay; very sparingly noted on Baleshare.
Salsola Kali L.
A few plants on the west shore of Baleshare.
Chenopodium album L.
A weed on Baleshare and Grimsay.
Atriplex glabriuscula Edmondst.
Coasts of Baleshare and Grimsay.
A. laciniata L.
On the same islands.
Suaeda maritima (L.) Dum.
In east of Baleshare.
Polygonum Convolvulus L.
Amongst oats, Baleshare.
P. heterophyllum Lindm.
P. aequale Lindm.
Both not rare on Baleshare and Grimsay.
P. Raii Bab.
On shores, Baleshare.
P. amphibium L.
In lochans on Ronay and Baleshare.
P. Persicaria L.
Common, Baleshare and Grimsay.

P. viviparum L.
On the Beinn Mhor mountain group, S. Uist.
Rumex obtusifolius L.
On all the islands.
R. crispus L.
On the same islands, but chiefly amongst stones on shores.
R. domesticus Hartm.
On Eilean Eallan, Loch Eynort, S. Uist.
R. Acetosa L.
Generally distributed.
R. Acetosella L.
Equally wide spread.
Euphorbia Peplus L.
Near Nunton, Benbecula.
Urtica dioica L.
On all the islands near old or recent habitation.
U. urens L.
On Baleshare near houses.
Myrica Gale L.
Although this plant only turned up around Loch Dun an t'Siamain on North Uist, it was found to be plentiful along the shores of lochans to the east of Beinn a' Charmain on Ronay.
Betula pubescens Ehrh.
It is perhaps worth noting that several trees of this species, with trunks 3 feet in circumference, grow on the Meall Mhor, Loch Eynort, S. Uist.
Salix aurita L.
Well distributed on Ronay, Grimsay and Stuley Island, occasionally occurring as well grown plants in thickets.
S. aurita × **S. repens.**
On Ronay only.
S. atrocinerea Brot.
On low grassy cliffs overlooking the sea, north of Bhuaile Mhor, Ronay and in a similar locality south of Loch an Fhaing, near the swamps, Grimsay; in both cases rare.
S. atrocinerea × **S. repens.**
On Grimsay with the parents.
S. repens L.
Widely distributed on all the islands. The segregates *S. repens* L. and *S. arenaria* L. were recognised on Baleshare.
Populus tremula L.
On Creag Mhor, on sea cliffs near Buaile Mhor and elsewhere, Isle of Ronay; many of the trees were very well grown.
Empetrum nigrum L.
Scattered on all the islands; even, as on Ronay, on sea cliffs.
Listera cordata Br.
Under bracken on Ronay and under heather on the banks of the stream leading up to Cadha Mhor, Isle of Barra.
Orchis latifolia L. (sec. Pugsley).
In damper areas amongst the dunes, Baleshare.
O. purpurella Steph.
On marshy ground on Baleshare, Ronay and Grimsay.
O. ericetorum (E. F. Linton) E. S. Marshall.
On Grimsay and Ronay not rare, but very sparingly in the north of Stuley Island.
O. Fuchsii Dr.
In the form of var. *hebridensis* (Wilm.) Heslop Harrison, on Grimsay and Ronay.
O. purpurella × **O. Fuchsii** var. **hebridensis.**
On Ronay only.

Coeloglossum viride Hartm.
Common the machair, Baleshare.

Iris Pseudacorus L.
Common especially near old dwellings Baleshare, Grimsay, Ronay and Stuley Island.

Allium ursinum L.
Above Bolum Bay, and in a form, with leaves two feet long, on a cliff along the south side of Loch Eynort, S. Uist.

Scilla non-scripta (L.) Hoffm. & Link.
Quite common on cliffs on Ronay, and on Stuley Island in hollows amongst bracken. Strangely enough, it has been noted in some abundance around the the machair transition lochs between Kilpheder and Askernish, and on bracken-clad banks along N. Loch Eynort, S. Uist.

Narthecium ossifragum (L.) Huds.
Not very common; Stuley Island, Grimsay, Ronay; rare, north-central Baleshare.

Juncus bufonius L.
Not common, Stuley Island, Grimsay, Ronay.

J. Gerardi Lois.
Sparingly near the sea on all the islands.

J. squarrosus L.
Generally distributed.

J. balticus Willd.
On Baleshare and now reported from Carnan to Kildonan, S. Uist.

J. effusus L.
On Baleshare; Nunton to Gramisdale, Benbecula and also on Ronay.

J. conglomeratus L.
Common generally.

J. maritimus Lam.
On Benbecula opposite Sunamul.

J. bulbosus L.
Frequent on all the islands.

J. articulatus L.
Also of general occurrence.

Luzula pilosa Willd.
Very rare on a cliff on Ronay; also around Loch Dun Mhurchaidh on Benbecula.

L. sylvatica Gaud.
On shady cliffs on Ronay and also on Stuley Island.

L. campestris (L.) DC.
On Stuley Island, Grimsay, Ronay and also Baleshare.

L. multiflora (Retz.) Lej.
On the same islands, with var. *congesta* Koch occasionally.

Sparganium simplex Huds.
Rare in lochs on Ronay.

S. angustifolium Michx.
In lochans on Grimsay and Ronay.

Lemna minor L.
In ditches, Gramisdale, Benbecula.

Triglochin palustre L.
On Ronay, Grimsay and Baleshare.

T. maritimum L.
Rare on Stuley Island and in the east of Baleshare.

Potamogeton natans L.
In lochs on Grimsay, Ronay and Baleshare.

P. polygonifolius Pourr.
In wet places, lochs etc. on all the islands including Stuley Island.

× **P. gessnacensis** Fischer.
In Loch na Liana Moire, Benbecula.

P. gramineus L.
In Loch Mhor, Baleshare.

P. alpinus Balb.
In a loch near Daliburgh, S. Uist.

P. perfoliatus L.
In Loch an Fhaing, Grimsay.

× **P. nitens** Weber.
In Loch Mhor, Baleshare.

× **P. Heslop-Harrisonii** Clark.
Also in the same loch.

P. Friesii Rupr.
In Loch Mhor, Baleshare.

P. rutilus Wolf.
In the same lochan.

P. crispus L.
In several lochans on Baleshare.

P. pusillus L.
In Loch Dun Mhurchaidh, Benbecula.

P. Millardii Heslop Harrison.
Lochans in Baleshare and in the north and west of Benbecula.

P. pectinatus L.
In various lochans, Baleshare.

Ruppia maritima L.
In enormous quantities in a brackish loch near Lidistrome, Benbecula.

Zannichellia palustris L.
In Loch Dun Mhurchaidh, Benbecula, not at all plentiful.

Zostera marina L.
Washed ashore on Baleshare.

Naias flexilis (Willd.) Rostk. & Schmidt.
Since our original records for this species, new to v.-c. 110, we have detected it in several lochs in North Uist; now we can report it from Loch Dun Mhurchaidh, Benbecula and a lochan just north of it. In the former loch it is very rare in the east, but becomes very abundant in the west, especially in that section parallel to the Market Stance—Balevanish road. New localities for the species on S. Uist are Lower Loch Ollay, and the west of Loch Ceann a'Bagh.

Eleocharis palustris Roem. & Schultz.
Common on Baleshare, Grimsay and Ronay; rare on Stuley Island.

E. uniglumis (Link.) Schultz.
On Grimsay and Ronay.

E. multicaulis Sm.
Grimsay, Ronay, Stuley Island.

Scirpus pauciflorus Lightf.
Very common generally.

S. caespitosa L.
On every island.

S. fluitans L.
Common in lochs, streams, ditches, etc., Baleshare, Grimsay, and Ronay.

S. setaceus L.
In damp places on Ronay and Benbecula.

S. Tabernaemontani C.C. Gmel.
In a lochan on the Isle of Ronay.

Blysmus rufus (Huds.) Link.
Only in Baleshare.

Eriophorum vaginatum L.
Ronay and Grimsay, common.

E. angustifolium L.
On Baleshare, Grimsay, Ronay, Stuley Island.

Rhynchospora alba Vahl.
In one locality, Stuley Island.

Schoenus nigricans L.
Common on all the islands.

Cladium Mariscus (L.) Pohl.
Known previously only from North Uist and Eriskay, it may now be recorded from Loch an Iasgair, S. Uist and a lochan just east of Loch Hermidale, Benbecula.

Carex pulicaris L.
On Grimsay.

C. arenaria L.
On the Baleshare dunes.

C. paniculata L.
Around the north end of Loch na Liana Moire, and on the south west of Rueval, Benbecula.

C. echinata Murr.
On all the islands.

C. nigra (L.) Reich.
Abundant everywhere.

C. juncella (Fr.) Fr.
Between Loch Iarras and the Allt Volagir, S. Uist.

C. flacca Schreb.
In a bog on the slopes of Askervein, south of Loch a'Chafain, S. Uist; also not rare on Baleshare.

C. pilulifera L.
Generally distributed.

C. panicea L.
Also plentiful.

C. binervis Sm.
On the moorlands of all the islands.

C. hostiana DC.
Not very common, Ronay and Grimsay.

C. flava L.
Generally not rare.

C. tumidicarpa Anderss.
On Grimsay and Stuley Island.

C. lasiocarpa Ehrh.
In a lochan just east of Loch Hermidale, Benbecula.

C. acutiformis Ehrh.
On Baleshare only; new record for v.-c. 110.

C. rostrata Stokes.
Around loch edges and in streams, Baleshare, Grimsay, Ronay.

Agrostis canina L.
Quite common generally.

A. stolonifera L.
On all the islands.

A. tenuis Sibth.
On Ronay, Grimsay and Stuley Island.

Ammophila arenaria (L.) Link.
Plentiful on the Baleshare dunes.

Aira caryophyllea L.
Generally distributed on the Islands.

A. praecox L.
As with the preceding.

Deschampsia alpina Roem. & Schultz.
Several plants at about 950 feet between Heaval and Hartaval, Isle of Barra.

D. setacea Richter.
In Loch Snigisclett, S. Uist.

D. flexuosa Trin.
On Ronay, Grimsay and Stuley Island.

Holcus mollis L.
Rarely noted; on Stuley Island.

H. lanatus L.
Quite common generally.

Sieglingia decumbens Bernh.
Generally plentiful on the islands.

Phragmitis communis Trin.
In a loch on Ronay and on Baleshare.

Cynosurus cristatus L.
On all the islands.

Molinia caerulea (L.) Moench.
Common in damp slacks on the moorlands, generally distributed.

Catabrosa aquatica (L.) Beav.
Rare on Ronay at stream mouths on the coast.

Dactylis glomerata L.
Now very common near Balevanish, Benbecula, introduced, no doubt, when the aerodrome was constructed.

Poa annua L.
Very common everywhere.

P. pratensis L.
Also generally plentiful.

P. trivialis L.
On all the islands.

Glyceria fluitans L.
Only on Baleshare.

G. plicata Fr.
In ditches in the Gramisdale division of Benbecula; new to v.-c. 110.

Pucciniella maritima (Huds.) Parl.
On Ronay and Baleshare.

Festuca vivipara Sm.
Plentiful except on Baleshare.

F. ovina L.
Common on all the islands.

F. rubra L.
Also generally distributed.

Lolium multiflorum Lam.
Near Lochboisdale, S. Uist.

Agropyron junceum Beav.
On the Baleshare dunes.

Nardus stricta L.
Quite common on all the islands.

Juniperus sibirica Burgs.
Well distributed on the Isle of Ronay.

Hymenophyllum peltatum Desv.
On the Creag Mhor, Isle of Ronay.

Ophioglossum vulgatum L.
Rare on Ronay, but exceptionally abundant on grassy slopes leading to the sea, Grimsay, and in dune slacks on Baleshare. The var. *polyphyllum* A. Br. was seen several times on Baleshare.

Botrychium Lunaria (L.) Sw.
Amongst grass on Baleshare.

Osmunda regalis L.
Around loch edges, on islets in the lochs and on cliffs, Grimsay and Ronay.

Pteridium aquilinum (L.) Kuhn.
Very plentiful everywhere.

Blechnum Spicant (L.) Roth.
Generally distributed on Ronay, Grimsay and Stuley Island.

Phyllitis Scolopendrium (L.) Newman.
Râre at southern entrance to Loch Eynort, S. Uist.

Asplenium marinum L.
Very plentiful on the Ronay sea-cliffs.

A. Trichomanes L.
Quite common, Ronay, Grimsay; rare on Stuley Island.

Athyrium Filix-femina Roth.
Common on Ronay, Grimsay, Stuley Island.

Dryopteris Filix-mas Presl.
Generally distributed on the islands.

D. aemula Brackenbridge.
In shady places on Ronay.

Thelypteris Phegopteris (L.) Slosson.
In a ravine on Ronay.

Polypodium vulgare L.
Common enough on all the islands but Baleshare.

Equisetum sylvaticum L.
In a ravine on Beinn nan Druidhneach, Ronay.

E. limosum L.
In lochans on Grimsay and Ronay.

Lycopodium Selago L.
Only noted on Ronay.

Selaginella selaginoides Gray.
On Ronay, Grimsay and Stuley Island; also on Baleshare on the machair and amongst the dunes in a very bushy form.

A DOZEN YEARS' BIOGEOGRAPHICAL RESEARCHES IN THE INNER AND OUTER HEBRIDES

by

J. W. HESLOP HARRISON, D.Sc., F.R.S.

The investigations carried out by the Department of Botany, King's College, Newcastle upon Tyne, in the Hebrides were commenced with the idea of preparing a comprehensive flora of the area. The results of the early work, which have been published in many scientific periodicals, were so inspiring and unexpected that our plans were extended in an endeavour to solve two closely linked problems: (1) the origin and history of the flora and fauna of the islands, and (2) the changes in configuration the area has undergone during the Pleistocene and Holocene Periods. Concerning the latter problem, there appears to be no agreement whatever amongst geologists whilst biologists put forward conflicting and totally unsatisfactory views. Balfour-Browne (1915), for instance, writes: " If Lewis has recently been part of the mainland which had been separated off by subsidence of an intervening land-tract, the water beetle fauna is just what would be expected," whilst Benson (1939) makes the pronouncement: " The study of island faunas should surely follow, and not precede, the study of the fauna of the adjoining mainland from which the island faunas were derived." These statements carry but little weight, the first because it is fatally compromised by the fact that it is based on the restricted evidence of one group, and the second because in its last phrase, it does not harmonize with facts; the island floras are not wholly derived from the mainland but, on the contrary, have, in respect to many components, a very different history. Richards (1935), tackling the matter from the zoogeographical standpoint, and dealing with island forms differing from their nearest relatives on the mainland, characterizes them as possessing a " fringing distribution," and defines them as " species which have retreated before an invading flora and fauna and have only survived in a fringe of western fastnesses." Our researches have led us to very different opinions, and, moreover, considered in connection with geological observations, have enabled us to reconstruct at least a portion of the movements which have shaped the Hebrides as we know them today, and, further, to state a time for the last severance of the islands from the mainland.

Let us consider, briefly, the agreed geological framework into which we must fit our biological facts. Of the Pliocene Period we can postulate but little except for one significant fact. At its close, just as today, the Hebrides, even if differing in detailed configuration, formed an archipelago. Concerning this, the 100 foot preglacial raised beach, marking the former sea level on Mull, Colonsay, the Treshnish Islands, and elsewhere, affords convincing evidence. Similarly, the late glacial 100 foot beach, so magnificently developed with its rock notches on the Isle of Rhum, demonstrates that, at the close of the Great Ice Age, the islands were much in the same position. Nevertheless, far reaching changes in surface contour and general shape have been experienced in the island area. all of which must be borne in mind.

Further, we have other complications in the form of a 25 foot beach and its sea caves, coupled with the present position of the second 100 foot beach, speaking eloquently of violent and repeated oscillations in the relative levels of land and sea. As will appear later, of the age of this 25 foot beach and of the last great period of marine transgression we have secured unassailable evidence. Obviously, whilst it seems certain that the Hebrides were islands both when the Glacial Period was ushered in and when it passed away, we have no proof that the late glacial rise in sea level marked their final separation.

Much has been written recently about the possibility of preglacial faunas and floras' having survived the Ice Age in the regions of glaciation, on icefree areas or otherwise, more especially on the Gaspé Peninsula, Quebec, and Newfoundland (Fernald 1925, 1929), and in Scandinavia (Hansen, 1903, Nordhagen, 1933, 1935, and Nannfeldt, 1935, and others). In addition, we ourselves (1916) have taken up the same position in explaining the anomalous flora of Upper Teesdale. This necessarily raises the same question in connection with the Scottish Western Isles. In that area, it is likewise more than probable that the present biota do not represent the outcome of postglacial immigration only.

Manifestly, at the onset of the Glacial period, the islands would possess, even if in an impoverished condition, the late Pliocene temperate flora and fauna of the rest of the British Isles, with a possibility that amongst these there remained relict forms, characteristic of the earlier Tertiary times when a continuous land mass stretched to the west and southwest of present-day Europe. Of the existence of such relicts, we have obtained undeniable evidence. Throughout the Outer Hebrides

(the " Long " Island), the Coll-Tiree and Rhum, Eigg and Canna groups, there flourishes the fine moss *Myurium Hebridarum* only found outside our area in the Azores, Madeira and the Canary Isles. As the moss does not fruit, it seems unbelievable that its remarkable, but orderly, distribution, both in the Macaronesian Islands and in the Hebridean habitats, should result from the workings of blind chance. Moreover, the bramble, *Rubus iricus,* found only in Ireland and the Hebrides, has its nearest relative, *R. Hochstetterorum,* in the Azores, whilst the water beetle, *Deronectes canariensis,* with several other mosses, liverworts and lichens, possess the same general range. Two deductions follow immediately, (1) that Myurium forms a relict species from an old Tertiary flora and (2) that it has persisted in, or near, its present stations throughout the Ice Age. This, in turn, implies that the same must hold true of the other organisms named.

That conclusion demands the existence on some of the Western Isles of unglaciated areas. Such regions we have detected on the Isles of South Uist and Harris in the Outer Isles, and on the Isle of Rhum in the Inner Group. In South Uist many ridges in the Beinn Mhor massif show no signs of ice action, and must have been thrust above the ice as nunataks when the glaciers prevailed. On these, at the head of Liadale and on Ben na Hoe, Myurium grows in plenty, accompanied by such plants as the Pyramidal Bugle (*Ajuga pyramidalis*), the Viviparous Knotgrass (*Polygonum viviparum*), the Mountain Sorrel (*Oxyria digyna*) and the Roseroot (*Sedum roseum*). Assessing these circumstances at full value, there seems no escape from the conclusion that, if Myurium with its marked southern affinities survived, then the Arctic-Alpines persisted with it.

Although, as we have seen, the Hebrides were cut off by the sea before the coming of the ice, the maintenance of such a state of affairs was impossible for two reasons. In the first place, the withdrawal of water from the sea during the build-up of the ice-fields automatically produced a fall of sea level of the type known as " eustatic." This clearly implies an expansion of some Hebridean land areas and the linking up of many others. Besides this, the weight of the huge ice load, nearer the centre of glacial development, depressed the earth's crust in such areas; this, in turn, produced a consequential outflow of the subcrustal magma to the periphery. Thus there was originated a second phenomenon, a compensatory isostatic uplift entailing an outward extension of our western areas. In short, the British area was not only linked to the continent, but also driven far out beyond its earlier western limits. Hence, when the flight of northern

animals and plants before the advancing ice was taking place, the Hebridean areas with their mountains, rejoicing in a climate tempered to some extent by oceanic influences, opened out for them a haven of refuge. Amongst the plants so crowding in were, undoubtedly the willow *Salix herbacea*, the Scurvy Grass (*Cochlearia arctica*), the Cushion Pink (*Silene acaulis*), the Alpine Saxifrage (*Saxifraga nivalis*), the Spiked Rush (*Luzula spicata*), the sedge, *Carex vaginata*, the Alpine Meadow Grass (*Poa alpina*) and the Alpine Hair Grass (*Deschampsia alpina*). However, in the end, the Hebrides were overwhelmed by a huge glacier moving from the mainland. Only mountains like the Beinn Mhor group in South Uist, Clisham in Harris, and Askival and Hallival in Rhum, pierced the ice field as nunataks. Upon these, just as Ostenfeld (1926) has demonstrated in Greenland today, and on ice-free cliff ledges, we picture the plants just named, with others of like predilections, as well as others enumerated previously, as surviving.

Of events during the bulk of the Quaternary Ice Age, it is idle to speculate, so few are the facts at our disposal. It is admitted by all that the Glacial Period was not one of continuous glaciation, for it was interrupted by several Interglacial Periods of more or less lengthy duration, when milder times supervened temporarily. Of these only the last needs consideration, and, even then, it seems quite possible that the events we shall now consider might be referred to one of the Interstadial phases of climatic amelioration which broke the continuity of the Upper or last Pleistocene Glaciation. Be that as it may, two agencies responsible for changing land levels made their influence felt. One of these lay in a raising of sea level due to water from the melting ice pouring back into the sea, and the other, isostatic in nature, and therefore affecting land levels directly, took its origin in the temporary removal of the ice load. In the end, equilibrium between the opposing influences was set up, leaving the Hebrides once again a more or less continuous land mass. Into this, hordes of immigrating plants and animals, diverse in type and from many sources, forced their way more or less deeply. In this fashion, the attenuated numbers of earlier glacial survivors were strongly reinforced.

Gradually, however, whether the interlude was interglacial or interstadial, the ice returned and glaciers pressed westward from the Scottish Mountains, thereby isolating the islands from the mainland by a huge barrier.

The question of the condition of the islands during closing stages of the Great Ice Age now becomes of supreme importance. If one relies on geological evidence alone, then the absence or

small amounts of recent drift, especially in the Outer Isles, and the position of the glaciers as gleaned from evidence on the mainland, taken in conjunction with the oceanic climate necessarily prevailing, point inevitably to the view that many must have been to some extent ice free. Upon such stretches, mountain, cliff, moor and machair, the last contingent of immigrants was compelled to live, and, if possible, withstand the changed conditions.

Here, again, we must return to the biological evidence. As was urged above, this element was composed of forms diverse in their requirements, woodland, moorland and other types of species all being represented. We must, therefore, answer for ourselves the question: are any animals and plants, whose occurrence is explicable on the basis of such isolation and survival, still in existence? The only possible answer accounting for the facts must assuredly be in the positive. We have only to point out to the long array of characteristic, and endemic, Hebridean plants and animals, which I have elsewhere termed "Eu-Hebridean" because they have evolved in the Western Isles. Typical of such amongst plants are the Hebridean Orchid (*Orchis Fuchsii* var. *hebridensis*), the Hebridean Honeysuckle (*Lonicera Periclymenum* var. *Clarkii,*) the Hebridean biotypes of the Bird's foot Trefoil (*Lotus corniculatus*) and of the wild roses, whilst amongst the animals, we have the Hebridean Woodmouse (*Apodemus hebridensis*), with its numerous subspecies, the Hebridean Thrush (*Turdus philomelos hebridensis*), the Hebridean Bees, *Bombus smithianus* and *B. jonellus* var. *hebridensis,* the Belted Beauty Moth (*Nyssia zonaria* var. *atlantica*), the special form of the Meadow Brown Butterfly (*Maniola jurtina* var. *splendida*), with numerous subspecies and varieties of all manner of living organisms.

Whilst *Bombus smithianus,* on the grounds of its relationship with bumble bees found in the Arctic, may have come in before or just after the Ice Age began, the remainder can only be regarded as of late or interglacial origin, long enough isolated on the islands to have diverged specifically or racially from the parent stocks. If *B. smithianus* represents an earlier invasion, its food habits indicate the co-existence of suitable flowering plants, an implication of some importance.

The Glacial Period passed with the restitution of huge masses of water, formerly locked-up in the ice cover, to the sea. This restoration and the resultant high sea level are registered on the 100 foot late glacial raised beach and rock notches. It is worthy of emphasis that geologists, when they do venture upon an opinion, regard its presence as marking the final break up of the Hebridean land mass.

However, the present elevated position of the beach indicates a later rise in land levels of no mean order, most certainly brought about by postponed isostatic effects. Whether or not it represents the maximum uplift seems a very different matter. Viewed in the light of our accumulation of biological evidence presented below, we are constrained to assert that it fails to do so.

If our interpretation of the later 100 foot beach on the Treshnish Islands, and of the extent of the contemporaneous marine deposits on the Isle of Coll is warranted, then, Coll, Tiree and Gunna, on account of their low altitudes, must have been reduced to mere skerries, quite incapable of supporting the rich flora and fauna with which they are now endowed. Amongst their plants, Coll, Tiree and Gunna possess several remarkable species, prominent of which are the Pipewort (*Eriocaulon septangulare*) and the Irish Lady's Tresses Orchid (*Spiranthes stricta*), both belonging to the so-called American element in the British flora. On these islands, too, fly the Irish subspecies of the Greasy Fritillary Butterfly (*Euphydryas aurinia* var. *praeclara*) and the Irish Burnet (*Zygaena purpuralis*). These species are all found in Ireland, but are completely lacking in the Outer Hebrides although the two Lepidoptera are known in a few relict stations on the Scottish mainland. The meaning of these curious distributions seems unmistakable; the forms involved must have passed from Irish refugia after the close of the Glacial Period to their present island stations. In other words, there must have existed a clear post-glacial passage over dry land.

For this to be possible, as has already been stated, a much greater rise in land level than the 100 foot beach allows must be granted. Fortunately weighty additional biological evidence points to the great probability of such an uplift, resulting from the same isostatic action as was responsible for the upward movement of the beach.

Amongst the organisms regarded as inter-glacial invaders are the Belted Beauty Moth (*Nyssia zonaria* subsp. *atlantica*), found on Rhum, Canna, Eigg, Muck, Tiree, Coll, Gunna, and throughout the Outer Isles, and the Common Winter Moth (*Operophtera brumata*) occurring on Lewis, South Uist, Coll, Rhum and Eigg. As both of these insects are characterized by wingless females, wholly incapable of flight, it seems incredible that they should have proceeded from their sanctuaries, where-ever these were located, otherwise than over a land surface. In addition, it is quite inconceivable that every colony of the Eu-Hebridean plants and animals has evolved independently on

the separate islands in which they are now to be found, and that the same evolutionary level has been reached in all. Clearly, the forms in question have originated on some major Hebridean land mass, probably lying to the far west, and have emerged over land areas to reach not only their present island habitats, but also, in some instances, the mainland of Scotland. Undoubtedly, on the evidence just adduced, the islands have been united amongst themselves, and to the mainland in post-glacial times.

A new line of approach, aiding in the solution of our problem, must now be followed. In many of our expeditions, examinations of peats have been carried out by pollen-analytic methods. Our results, as far as forest trees are concerned, demonstrate an orderly immigration of forest trees in Boreal and Atlantic times even as far as the Outer Isles. In particular, attention is directed to the fact that, beginning at zero when the deposition of peat was initiated in early Boreal times, oak pollen reaches the high level of 20% in the Atlantic Period (Zone VII of Godwin) in South Uist and Barra. Considering the mode of dispersal of acorns, and their low viability, it appears to be impossible that the oak should have invaded the Outer Isles otherwise than over dry land in Boreal times over 8,000 years ago.

Again, in many islands, as for example, in Harris (Outer Isles), Rhum, Raasay and South Rona (Inner Isles), the holly (*Ilex aquifolia*) still grows freely whilst ivy (*Hedera Helix*) is even more abundant and wide-spread. These plants are well-known to have been on the move in the Western Europe area in Boreal and Atlantic times (Faegri, 1940, 1943; Iversen, 1944). Once more a continuous stretch of Hebridean land of postglacial development is required to account for the present distribution of holly and ivy in the area.

Taking cognizance of all facts, there is no escape from the conclusion, drawn from the most powerful of biological evidence, that the 100 foot beach has at some point in the warmer Boreal Period lain far above its present situation. The isostatic recovery responsible for that elevation, by the consequent development of a continuous land mass west of Scotland, not only afforded the Eu-Hebridean organisms opportunities of free movement within the area but, also allowed viviparous lizard, the toad, the palmate and smooth newts, the moths, *Orthosia gracilis, Omphaloscelis lunosa,* the butterfly *Brenthis selene,* the bee, *Bombus agrorum* and many other forms, to crowd in from the south and west. These migrations took place almost at the same time as the immigration of the American element from Ireland.

At other points in the glaciated European areas, where the disappearance of the ice had been delayed longer, isostatic recovery in the end made its influence felt. There the land rose steadily, accompanied by an inflow of the subcrust from marginal zones and a consequent lowering of their levels whereby, firstly, the Outer Isles were cut off by the sea, followed by the Coll-Tiree group and, lastly, the Rhum-Eigg series. In this longer duration of the link between Rhum, Eigg, Canna and Muck and the mainland lies the explanation of the greater number of species of southern proclivities they support.

Of the date of the last great marine transgression which succeeded these movements, and doubtless depended upon a eustatic rise in sea level produced by the disappearance of Scandinavian ice, we have a very pretty proof In one of our peat borings, made (Blackburn 1940) on the Isle of Soay, in addition to the usual peat samples, the tool brought up a foot and a half of grey brown mud, containing great quantities of marine diatoms, indicating that it marked the transgression represented on Rhum and elsewhere in Scotland by the 25 foot raised beach. Now this mud, by its pollen inclusions, revealed that it had been deposited between the end of the Boreal Period and the close of Atlantic times. That not only dates the transgression, but shows that it attained its maximum during the Atlantic Period and persisted to its end. Indicative of this same submergence are the submerged "forests" of Vallay, North Uist, South Uist and Barra and also the submarine peats off the western shores of the same islands.

However, the present position of the beach points to a more recent rise in land level, representing a local restoration of the earth's shape after previous distortion. Despite this, in the Outer Isles, the sea is still gaining ground. Not only do local traditions assert that certain areas, as, for instance, those adjacent to the Isles of Pabbay and Boreray in the Sound of Harris, and to the Isles of Fiaray and Fuday, off the north of Barra, have been overwhelmed by the sea within the memory of man, but, corroborating this evidence are the many drowned land lochs encountered throughout the Long Island. Over and above this, if one gazes at Berneray, Mingulay, Pabbay, Sandray, Lingay and Flodday from Heishival on Vatersay, or on the landscape from Rueval on Benbecula, the impression one gains is that of lands recently submerged and of such action still in progress today.

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Description of the determination of the "Longitude of the Observatory of the University of Durham, as found by transmission of chronometers to and from Greenwich by railway in the months January and February, 1851."

Communicated by

E. F. BAXTER.

The following is a copy of the manuscript account by R. C. Carrington, Observer. It is written in a leather bound note book on the cover of which the title " Longitude of the OBSERVATORY AT DURHAM as found by transmission of chronometers in the year 1851 " is stamped and gilded. After the description here given there follow 52 pages of readings and reductions with occasional notes, all done in a style which inspires confidence in Mr. Carrington as an accurate and careful worker. A second in this latitude is about 880 feet and the result is given to the hundredth part of this. Dr. Whiting, in his History of the University, speaks highly of Mr. Carrington who was Observer from 1849 to 1852 when he left owing to unresponsive Curators. He subsequently did such good astronomical work that he was awarded a gold medal of the Royal Astronomical Society.

THE MANUSCRIPT

" When the Observatory was first established in 1841, its approximate Longitude was found by a trigonometrical measurement of its distance west of the Cathedral as given in a general survey, and 6 mins. 18 secs. neglecting fractions of a second, was adopted to start with, and this value has since appeared in the Nautical Almanack and elsewhere.

In the succeeding years, observations of the Moon and Moon culminating stars were gradually accumulated, principally in the times of Mr. Beanlands and Mr. Thompson, and in the preface to the volume of observations edited by Mr. Thompson, the comparisons of them with corresponding observations at Greenwich are stated: the whole number being 39 by Mr. Beanlands and 15 by Mr. Thompson. To these I have since added later observations of Mr. Thompson, for which the corresponding

Greenwich observations had not then appeared, making up in all about 25 observations by Mr. Thompson. The whole of these 64 comparisons indicate 6 mins. 19.0 secs. as a result, with a still considerable probable error, about 0.6 secs., the average uncertainty of a single result appearing to be about 3 or 4 secs.: not taking into account possible sources of error due to a difference in observing a limb from observing a star, or to the effect of irradiation.

An opportunity of effecting a direct comparison of chronometers had long been looked for, and at the meeting of the Observatory Syndicate in December, 1850, it was agreed that application should be made to Messrs. Reid of Newcastle for the loan of chronometers and that the comparison should be at once carried out.

Ten or twelve pocket chronometers were applied for, of the best construction, but a difficulty was met in supplying them, Messrs. Reid not dealing in that make, and eventually three marine box chronometers were sent, and three pocket chronometers hired from London of different makers, which last proved insufficient and inferior. The box chronometers performed well on the whole. They were received from Newcastle on January 4th, and carefully rated daily by comparing each with the Transit clock between 10 hrs. and 11 hrs. by the method of coincidence of beats: at first three or four comparisons of each were made till I became accustomed to it, afterwards two were taken, the second as a check on the first; and in reducing the best of the two was retained.

Then daily comparisons were made from January 5th to 17th. I left Durham by the night mail train for London on the 17th at 10 p.m. arriving at London at about 10 a.m. on the 18th. I then left the case with a servant who met me by appointment while I procured a spring carriage, and then I went on with them to Greenwich, by Hyde Park and Lewisham, in order to avoid the stones of London, and arrived at Greenwich shortly after 2 p.m. when comparisons were made with the Greenwich Transit clock. I then waited, the sky being clear, till I had secured transit observations myself for the clock error, of these four were made available, some being lost from my not being used to the instrument, the larger and newer Zenith circle only lately erected. While at Greenwich the chronometers were hung in the chronometer room and compared shortly after noon with the mean time clock Dent by the assistants in their regular practice, excepting on the 19th and 20th, when by Mr. Main's consent they were carefully compared by Mr. Duntain with the Transit clock, and on the 25th, when being at Greenwich I made a

similar comparison myself. I held myself in readiness to leave for Durham on the first evening after the 22nd, on which I could first secure clock star transits, and waited in this way till the afternoon of the 27th, when I got eight stars and left Greenwich at 7 p.m. and London by the night mail at 9 p.m., arriving at Durham the next morning at 9 a.m. The chronometers were compared with the Durham Transit clock soon after arrival and a sufficient number of clock stars secured the same day: in this way the first joining was rendered independent of the personal equation of the observer. The three box chronometers travelled in one deal case padded, and made of a size just to contain the three and to go under the seat of a first class railway carriage: the spaces between them in the case were filled with horse hair stuffing, and before putting them in, they were made fast in their gimbals by the catch provided. The box was padded on all sides within, and at the bottom outside was provided with three padded feet on which it rested without swinging. It was carried between the trains and carriages between two men, who were careful not to swing it more than possible in walking: and on no occasion during either journey did it encounter the slightest blow. The chronometers were rated daily as before after arrival till the end of January, when the work of the first result is considered to end.

I then reversed the Transit from the East to the West in order to eliminate in a second comparison any source of error due to a small uncertainty of the collimation error; and the chronometers were again rated daily till February 4th, when I left Durham the second time with them by the night mail, arriving at Greenwich at 2 p.m. the next day. No stars were observed on this day, the sky being densely clouded. I left Greenwich the same evening by the night mail, and arrived at Durham as before at 9 a.m. on February 6th: having made two comparisons of the chronometers with the Greenwich Transit clock, one on arrival and the other on departure. I succeeded in getting satisfactory observations for clock error at Durham on the 6th: so that the only uncertainty for the second journey lies with the clock error at Greenwich and the difference of personal equation applied. Ten clock stars were observed at Greenwich on the 4th, and twelve on the 6th: the rate is assumed to have been equable between these days and finally a correction of 0.10 secs. has been applied which was the personal equation given by my eight stars on January 27th compared with fourteen observed by Mr. Main and reduced to the standard. From February 6th to 8th the chronometers were rated as before, but twice each day, and then returned to Messrs. Reid.

Of the pocket chronometers no account will here be of value though as much labour was spent upon them as upon the three others in comparisons and reductions: it is only necessary to give the following specimen of the successive daily rates of one of them to shew that it would be useless to base anything upon them 69, 85, 80, 79, 70, 93, 82, 95 secs. joining. A pocket chronometer by Webster, belonging to Professor Chevalier, was also put in use on the second journey, its rate was pretty good, but the result was unsatisfactory, and it was not thought worth while to mix the results. The names of the chronometers used were:— Hornby No. 771, Reid No. 1109, Harrison No. 476. The three pocket chronometers rejected were:— Jackson No. —, Hatton and Harris No. 651, Barrand No. 882.

Any other remarks are added in the course of the reductions which follow. It is only necessary to add that all the rating, comparing, and reduction of the observations was done by me throughout.

(Signed) R. C. CARRINGTON."

The longitude of the Observatory as found by this work is given by Mr. Carrington as 0 hrs. 06 mins. 19.75 secs. West.

Ore-hearth lead smelting in the 17th & 18th Centuries

By

A. RAISTRICK, M.Sc., Ph.D.

Lead smelting in this country has, in the course of centuries, passed through three principal phases, according to the type of furnace in use. The earliest and most primitive is of course the well known and almost universal "bole-hill." At some period before the eighteenth century this had been superceded by the small blast hearth, out of which grew the true "ore hearth," which in turn gave way in many areas before the adoption of the "cupola" or reverberatory furnace. Of the periods of transition when one method was being tried against another and when experiments in improvement were in progress, on the results of which major changes in smelting practice were based, little has been written. This paper is intended to place on record a few documents and suggestions which have some bearing on this matter.

Descriptions of bole-hill smelting are available from many sources[1] but most of them are of necessity based upon excavation and examination of ancient bole-hill sites or on verbal report collected by early and mainly non-technical writers, thus providing little precise information. In general the "bole-hill" type of furnace depended upon the wind for its draught, but there are indications that this was not always the case. In the well known de Lacy Compotus for the year 1303-4 the accounts for the lead mines near Baxenden in Rossendale, Lancs., include a few items which can usefully be considered together.
translated) [2]

91 loads 6½ dishes of Ore bought from the miners 9 dishes make a load. price per load 22d.	8	8	1¼
Cutting down and cutting up wood for burning the said ore		7	5
Carrying the said wood and ore to the Bole		8	8½
Expenses of burning the said ore	1	16	6
Making a pair of bellows anew for burning the said ore		7	8
Making and binding with iron a pair of scales for weighing the lead and making other necessary utensils ...		2	6
Making a shed for the lead and an enclosure for the ore ...		5	8

[1] Watson R. Chemical Essays 2nd edit. vol III, 1738 pp. 265ff.
Raistrick, A. *Trans. Newcomen Soc* VII, 1927, plt. XIV pp. 81-96.

[2] De Lacy Compotus. *Cheetham Soc. O.S.* vol CXII, and also quoted in Tupling G. H. Economic History of Rossendale, 1927.

Here the bellows are definitely stated to be for burning the ore, which was carried to the Bole, " carianda usque *le Boole.*" Unfortunately like most of the accounts of the Middle Ages the measures of ore are not precise and most materials, e.g., the wood, are specified only by a money valuation, so that no ratio between fuel and ore can be worked out.

The print of Burchard's Furnace described by Mr. Young[3] shows a modified and improved bole-hill furnace actuated by bellows and called the old method in contrast with the new and undoubted " ore hearth " furnace with two wheel driven bellows. The date of this is 1582. It seems that the small blast furnace which came to be known as the ore hearth was in use in Germany during the sixteenth century, and was certainly used by the German miners at Keswick soon after 1565. In most of the North of England an intermediate form seems to have prevailed, developed from the bellows-blown bloomery or bole-hill and only developing into the ore hearth in the early eighteenth century when it was in many areas applied to slag smelting.

An early account which is usually referred to as a description of the ore hearth, that of Martyn in 1729[4], clearly describes an intermediate stage between the bellows-blown bole and the ore hearth. " The furnace which Mr. Martyn saw near Wirksworth was very rude and simple, consisting only of some large rough stones, placed in such a manner as to form a square cavity into which the ore and coal are thrown stratum super stratum; two great bellows continually blowing the fire, being moved alternately by water. He saw no other fuel used on this occasion but dried sticks which they call white coal. They generally throw in some spar along with the ore which it is thought, by imbibing the sulphur, makes it flux more easily. They frequently throw in also some coak or cinders of pit coal, because they think it attracts the dross and so makes it separate easier from the lead. When the ore is melted it runs out at an opening in the bottom of the front part of the furnace, through a small channel made for that purpose, into a cylindrical vessel, out of which it is laded into the mould. The dross of the ore, on smelting, is called slag. The slag is afterwards smelted again with coak only and the lead obtained from it is called slag-lead."

3 *Trans. Newcomen So.*, VII, 1927 pp. 94-96

4 Mr. J. Martyn. *Phil. Trans.* XXXVI, 1729. An account of some Observations relative to natural history made in a journey to the Peak in Derbyshire. No 407.22.

If Pilkington's description of the ore hearth is placed alongside this[5] it is clear that he has used Martyn's account in the main, but a few details have most likely been added from his observations or from local verbal descriptions. The dimensions of the hearth are an addition: "It consists of large rough stones placed in such a manner as to form an oblong cavity about two feet wide, fourteen long, and two deep into which fuel and ore are thrown in alternate layers." Commenting on the slags he says "They are accordingly put into another furnace called a slag furnace. The heat required for smelting them is produced by a fire made with coaks, and is more intense than in the former instance." Speaking in 1789 he says "I believe there are only two hearth furnaces in Derbyshire. . . ." the main part of the smelting being by reverberatory. It is in these accounts that we see the first separation from the bellows-bole furnace of two distinct lines, the ore hearth and the slag hearth. The simple furnace described by Martyn is indeed rightly called a "hearth" and it seems as though this name is correctly continued in the ore hearth which remains shallow and partly open, but not in the deeper slag furnace, which is more like a small blast furnace.

The details of the ore hearth are available in many technical descriptions[6] and the nomenclature of its individual parts is precise. Of the names associated with the ore hearth exclusively, one is that of the "work stone," the fore part of the hearth, onto which much of the partly melted ore and sticky slag can be drawn to be picked over and "worked" during the run of a smelting. The "hearthtsone" and "backstone" are also important parts. These names are met with in many later accounts relating to ore hearths, but the earliest use of them known to the author, is in some fragmentary accounts for lead smelting at Grassington in Yorkshire. Unfortunately these accounts consist only of jottings made at the works, to be copied later into a journal or book now lost, but were made by the smelter.

20 Sept., 1658. Payd to John Lupton and his ptns for choping and drying wood for smelting 20 tun of lead	7	10	0
28 Sept., 1658. Payd to John Smith for		18	0
payd John Smith for getting 10 kills of chopwood into the kill		5	0
and for getting some *hartstones*		16	0
and for mending the *workstone*		2	0
May 1658. Payd George Smith for a bill of Repayres about the Lead Mill dam		8	0
payd George Smith for mending the Bellows		14	0
payd George Smith for several workmen makinge of ye Chimly and the milldam		17	0

5 Pilkington, J. A view of the present state of Derbyshire. 2nd edit., 1803, Vol. I p 119. First edition printed 1789.

6 Forster, W. A Treatise on the Strata from Newcastle-on-Tyne to Cross Fell. 2nd edit 1821. p. 376 and plt. 10.
Percy, J. Metallurgy of Lead. 1870 pp. 278-293, figs. 84-95.

These fragments agree very well with the picture of an ore hearth similar to that described by Martyn, but with hearthstone and workstone already christened, and with "dried sticks" or "white coal" as the main fuel. The "kill" is probably a drying kiln for the wood, there being no mention in these earliest accounts of charcoal. The mill dam and bellows complete the picture. As throwing some light on the organisation and scale of the fuel supply for the early ore hearths, in relation to quantity of work, there is a very detailed account of one year's expenses, that is worth quotation in full, and which follows.

An Acct of the Disbursmts at Grissington Mill since the 7th day of May, 1701, untill the 22nd of May, 1702—as followeth:—

	£	s.	d.
Payed Roger Taylor and ptners for chopping and drying 57 loads at 7d p. load in Grasswood	1	13	3
Wm. Bumbie for felling in Grasswood		3	0
for 26 Load of Coals from Thorpe		8	10
Tho. ffountaunce and ptners. for chopping and drying 60 load at 7d p. load in Grasswood	1	15	0
then for 50 load more at 9d. p. load	1	17	6
then for making a kill hole		5	0
for 6 load of coals from Thorpe		2	0
Wm. Atkinson & Bumble for chopping and drying 35 load at 8d. Load in Bolton land banks	1	3	4
first quarter Land Tax at 3d. p. £		15	6
the 2nd quarter Land Tax at 3d. p. £		15	6
for carting of 4 pieces of lead to Bolton Church for the Lord's use		1	4
Luke Baton for 28 load of coals		9	4
Thoss Ffountaunce & John Demaine for chopping and drying 212 load at 8d. p. load at Bolton Lande parke ...	7	1	4
both parsons for Smelt Mill composition	2	0	0
6 load of coals from Bordley		2	0
for tallow and candles		1	1½
for mending the bellows with leather		1	6
Luke Baton for 21 load of coals		7	0
pd. him for 3 load of lime		1	6
Jo Green for 3 days walling at the Mill end		4	0
the 3rd quarter Land Tax		15	6
Wm. Tillison for getting and hewing stones and for work at the mill		11	2
in expences with the workmen			8
James Marble for mending the bellows			4
Geo. Ewin for half a days work at the mill			6
Wm. Wilkinson for leading stones and lime		3	6
John Davis for 2 days helping masons		1	4
John Layland for 4 new sumps		10	0
Rich. Pearte & Tho Pulman for felling and chopwood in Grasswood on ye North Side at 9d. p. day		3	9
Expences with woodcutters		1	0
6 lbs. tallow for new bellows		2	2
Tho ffountaunce for one day with Bellowsmaker		1	0
for carriage of hydes, oyle and tallow			6
Francis Skirrow for making the Bellows	2	7	0
expences with them that time		2	6
Wm. Harrison and ptners. for work at the Mill		12	0
4th quarter Land Tax		15	6

John Inman for work at Choppkill		2	6
Tho ffountaunce for making the same		2	6
Luke Baton for 37 loads of coals		12	4
Tho ffountaunce and ptnrs. for chopping and drying as much wood in Grasswood as smelted 23 Ffds. 5 pieces and 4 stone at 6d ye Ffodder	6	19	8
Ste Pearte and Geo Browne for carriage of Chopwood fr Bolton Wood for as much as smelted 36 Ffodder 11 pieces at 7d ye Ffodder	12	15	10
Ste Pearte and Tho Brown for carrge fr Grasswood for 42 Ffodder 12 pieces 6 stns at 3d. ye Ffodder	6	7	10
Alld to myself for 18 load of chopwood at 6d. ye ld. ...		9	0
Henry Hall and ye Smith as p. bill	1	4	7
Ste Browne Smith as p. bill		5	4½
James Helstone for 2 days felling wood		1	6
Charges when warrant was sent to Connystone		1	0
For 2 hydes for bellows and other things for bellows ...	2	16	1
Craves to be allowd for sallary for year 1701	4	0	0
Craves also the usual allowance towards Charges ...	1	0	0
	40	18	10½
	21	15	9½
Totall of disbursments ...	£62	14	8

Smelted Ff. P. St.
79 3 3

In this account there are a few items that may need a note before any detailed analysis is made. The item for "both parsons. . ." is a composition of £1 each payed instead of royalty on the smelt mill, to the two incumbents of the divided rectory of Linton. The coals from Thorpe and Bordley are true coal, from the coal seams in the base of the Millstone Grits which were extensively worked in the seventeenth and eighteenth centuries. The item to John Leyland for four new sumps, may refer to the cast iron pans in which lead from the ore hearth is caught before ladling into the moulds; these pans are often called "sumpter pots," and other variants.

There is again no suggestion of charcoal as fuel, but the association of chopped wood and the "kill" with the charge for drying, agrees with "white coal" as the principal firing. The true coal may have been used in the drying kilns as well as at the smelt mill. Once again, any equation between the amounts of fuel and ore smelted is made impossible by the form of the accounts. Of coal, 124 loads were provided, and of wood two quantities, first 432 loads chopped and dried, and in addition "as much wood as smelted" 59 fodder 16 pieces and 4 stones of lead. From the figure of the total lead smelted, this leaves 19½ fodders of lead for the 432 loads of dried wood. If these figures could be used, they indicate that 432 loads of wood were used to produce 429 cwts. of lead, the fodder being at Grassington, 22 cwts. What was the weight of the "load" we do not know.

Of the " kill " we have no details, but it is possible that remains of these drying kilns are still to be seen in Grasswood, where among hut circles and other remains of the Iron Age and later structures, there are in one part of the wood that is all plantation with no original woodland or underwood left, certain stone structures that are obviously more modern. These consist of a deep bowl shaped hollow, about twelve to fifteen feet diameter at the top and six to eight feet deep at least, lined out with carefully built dry stone walling, and paved on the bottom. On one side there is a narrow opening going down to the floor level and approached by a sloping passage, or more commonly, where these are built in the hill slope, by a level passage from the low side. Nothing has been found in these places but fragments of charcoal and coal ashes, and they have been regarded as possible " elling hearths " for making potash lye from brushwood. The discovery of these kiln accounts, however, suggests that they are probably the wood kilns built for the supply of white coal to the smelters. The account includes items for making and working at the " chopp-kill " and for making " a kill hole," five shillings in each case.

A form of blast furnace or slag hearth was in use in North Wales by Mr. Mostyn, before 1702, and was adopted by the London Lead Company at their mill at Gadlis, Flint, for slag smelting, but for ore smelting they introduced the reverberatory furnace.[7] Their experience with this furnace was such that they introduced it at all their smelt mills in the North of England, and before 1750 it had come into general use in Derbyshire, almost completely ousting the ore hearth and all other forms of furnace. In the Alston Moor district the ore hearth survived alongside the reverberatory furnace, and in Yorkshire, the ore hearth remained for long the chief smelter in use. In Wharfedale it was not until about 1800 that the Duke of Devonshire's agents introduced the reverberatory or " air " furnace, at the newly built mill still called the " Cupola " on Grassington Moor. It seems a fair generalisation that can be made at this point, as well as later, that the ore hearth, with its extremely simple structure and its easy processing, was ideally adapted to smelting small quantities of variable ores. The amount at one shift was small, easily handled by one or two men at the most, and the resultant lead was of good quality. The reverberatory furnace was a much larger structure, dealt with far larger quantities, could be run as a continuous process, and demanded far more skill and more uniform ores. Essentially the ore hearth remained the mill of the small tributing miner, the reverberatory being the concern of the larger companies. Where silver rich ores occurred and lead refining was of prime importance, the reverberatory again had considerable advantage over the ore hearth.

[7] Raistrick, A. *Trans. Newcomen Soc.* XIV, 1935, pp. 119-162.

During the eighteenth century the form of the ore hearth became standardised, and descriptions of its parts and the costs of erection show a fairly standard type to be in use over all the mid- and north-Pennines. The best contemporary description is given in a manuscript account of ore treatment and smelting that was prepared by James Mulcaster, one of the agents of the Commissioners and Governors of the Royal Hospital for Seamen at Greenwich. A copy of this manuscript in the library of the Literary and Philosophical Society of Newcastle-on-Tyne, contains internal evidence that the original was written in 1780, and it will be useful to take from this MSS the description of the ore hearth.

An Ore-Hearth Smelting

I call it *Ore Hearth Smelting* to distinguish it as well from what is done in the Slag Hearth as from another mode of Ore Smelting I hear Mr. Gilbert calls *Copalo-Smelting*, but which I always called *Furnace Smelting*, a mode upon which, as I have never seen it I cannot say anything, but having been long and intimately acquainted with the other I shall endeavour to describe it.

The form of the smelting hearth being shown in the accompanying sketches I now proceed to inform you that to commence smelting, the bellows being put in motion, the Hearth is filled with Peats, a sort of wall is made of the same in the front of it, and a fiery or already kindled one is placed among them just before the Muzzle of the Bellows, from which a conflagration catches, and is presently communicated to every part of the Hearth; to increase which and to give the fire more fierceness some shovels-full of coal are cast upon the top after which and when it is seen that such mixed fuel is sufficiently in combustion, a quantity of *Brouse* is also given upon the top, which Brouse is a mixture of Ore imperfectly reduced to Lead and Slag Coal cindered or half burned, and Lime, being a stock formerly the contents of the same Hearth and wch has been drawn out of it at finishing its preceeding fit or working . . . . . this Brouse with now and then a shovel-full of fresh coal is at intervals given until in about half an hour the whole and also the filling of Peats those in front excepted, is expended, then those last being now kindled are taken down and placed in a cast iron pot called the *Sump* in order that it may be sufficiently heated for the reception of the lead when that begins to flow which it does not till several *Watchings* and *Settings-up* are performed and commonly not till some raw ore is given and the Brouse has acquired such a degree of heat as will dissolve 4 or 5 cwts. of Lead a quantity wch is generally left at the end of every *fit* or *shift* of working, in the bottom of the Hearth called the *Pan*, where such quantity must be and in fusion too before any lead unfreed can issue. But this quantity now being increased by the constant trickling down between the interstices of the incumbent brouse of such other lead as is by this time exuding from the ore . . . . . this first receptacle of it overflows and gives the workmen notice that they may be tapping. take as much of it away as they suppose is made or extracted every fire by which Fire is meant the time between the Watchings and Settings-up of the Hearth as they are called.

One of the smelters for they always work in pairs, with a strong poker first stirs or heaves up the whole of the brouse in the hearth then draws out about one half of it upon a sort of shelf or apron of cast iron which lies joining the front or foreside of the Hearth. This is called the *Workstone* and in it is a grove or gutter which communicates with the

Pan of wch this workstone forms one side, thro wch the lead passes to the Sump from wch it is cast into Pig-moulds. This performance is called *Watching* and during the time this is doing the other workman with his shovel clears the Muzzle of the Bellows of such Brouse as is against it and places his Peats wch done the two men join in casting off the Slag. serving with the necessary Coal and Lime and replacing the Brouse in the hearth by casting it in at or upon the top, wch being made level so much fresh ore as they judge may be digested before another Watching is given upon the top, where it undergoes a temporary roasting wch fits and prepares it a little for its being brought into the most vehement part of the fire. These watchings and settings-up are generally performed once in every five Minutes so that the labour of smelting seems to consist of an often repeated pulling down and making up of the same fire for wch I shall endeavour to account . . . .

Without a frequent stirring up the whole mass of the Brouse tending as it always is to vitrification, would soon become so compact a body that neither could the fire agitated by the Bellows pervade every part and cranny of it, as it ought to do to operate rightly upon it, nor could the Lead as it perspires from the Ore or unexhausted parts of the Brouse in the Hearth, find a passage down thro it to the bottom, where it ought to be speedilly to be out of danger, for whilst it is suspended in the upper parts of the Hearth, it is in a state of evaporation and waste . . . .

In discussing the distribution of the wind by the interposition of a peat before the bellows nozzle, he describes the hearth as a "square of 26 Inches in Length by 22 Inches in Breadth and 14 or 16 Inches in Depth," and this leads one to believe that in Pilkington's account of the hearth, the dimensions which read as two feet by fourteen by two feet, should be read as fourteen *inches*. In opening his next section of the manuscript, Mulcaster says:

"The operation of smelting in a Slag Hearth differs from that of an Ore Hearth in this that in the Ore Hearth the Ore to be operated upon does not undergo an entire liquefaction or fusion of all its parts, but only a partial one by having its lead or the greater part of it sweated out of it."

The general description just quoted is very close indeed to that given ninety years later by Mr. Weston, from Keld Heads Smelt Mill, Yorkshire[8] and by Pattinson as being in use in Alston Moor about 1830. It seems therefore that the form of the ore hearth and method of working made little change in the course of the hundred years from about 1780. The shift worked was usually 12 hours or 15 hours, and in that time 4½ to 5 bings (8 cwts.) of ore was treated. In an area like most of the Yorkshire mining fields, where large numbers of small partnerships of miners were working on tribute, producing small parcels of ore, with liberty to smelt at any of the royalty owner's mills and paying dues in smelted lead, it was very convenient to have several small mills equipped with one or more ore hearths, to which the miners could go. That this was the general plan is clear, by the large number of such small mills built or in operation during the eighteenth century.

[8] Percy, J. Metallurgy of Lead. 1870 pp. 278-289.

In one of the Grassington Moor account books there are a few notes interpolated for reference, relating to mills, as follows:

1741 July 1. Finished ye New Hearth and began to Smelt that day. The New Bellows at both Hearths were sett up 15 Nov. 1749. The wheel at Low Mill which carries two Hearths was made Oct. 1761. The New Hearth erected at the expence of the Coalgrove Co. was finished the 4 Sept 1754 & began smelting a few days after. The New Mill on the Moor built at the expence of the Coalgrove Beck Co. was finished 2 Oct 1756 and begun smelting a few days after but afterwards paid for by my Lord and now in his direction. Mem: that on one day in Nov. 1754 there was six hearths smelting all at once Metal wch was gott on Grassington Moors & was as follows

Mr. Bradshaw & Co. Coalgrove Beck were smelting at ye 2
Jas. Swale & Co Ripley Vein Hearths at Girston Mill
Robt Pickles & Co Blew Levell also
Mr Readshaw & Co were smelting at Kettlewell Mill,
John Ayrey & Co were smelting at Buckden Mill &
Robt Waterhouse & Co, Mexico. were smelting at Kilnsey Mill.

The smelt mills at Buckden, Kettlewell and Kilnsey were fairly old, that at Buckden being at work in 1699 and the others soon after. The "Low Mill," Grassington, was also early at work, the New Mill on the Moor overlapping then replacing it about 1770. The quantities smelted at these various mills varied tremendously. In 1704 Buckden Mill smelted 56 fodders and 63 fodders in 1705, the fodder being 21 cwts. At Grassington Mill in 1698 the figures are:—

	ff.	q.	st.
smelted for several psons	111	1	8
dues for same smelting	24	14	4
sold to defray ye chardges of ye mill	6	10	7

By the middle of the century the output at Grassington Mill had reached fairly high figures, remembering that all was by ore hearths, and prior to the new hearth noted above.

	Tn.	Pc.	St.
1744	427	5	5
1745	278	8	6
1746	295	18	6
1747	261	7	5
1748	312	2	3
1749	322	8	3
1750	463	12	5
1751	373	16	3
1752	319	19	6

A note against some of these quantities shows that wood was still being used along with peat, and a contemporary plan shows the smelt mill with two "peat houses" adjacent to it.

In the Alston Moor district, a similar distribution of small mills using one or two ore hearths, well spread over the area, was the rule, except within the leases of the London Lead Co. Towards the end of the eighteenth century, there were, in the London Lead Co. mills 13 reverberatory furnaces and 18 ore hearths, but in the rest of the area 11 mills operated 39 ore hearths, 10 of these being in the Langley Barony Mill of the Greenwich Hospital and the remaining 29 in 10 small mills. In the Yorkshire Dales north of Wharfedale, a similar practice was common, a fairly wide mesh of small mills with one or two ore hearths being maintained over a wide district, with a larger central smelt mill at the head of the largest royalty.

From the accounts of the operation of the ore hearth, the advantages of this system are clear. The hearth could be fired with peat, dry wood, coal, and cinders, mixed fuels in which peat took the foremost place. The operation could be started and under way in a very short time, lead production starting soon after the fire was lit and the bellows applied. Temperatures were much less than in the reverberatory furnace, and smaller bellows, shorter chimney and cheaper fuel were quite satisfactory. A single shift could deal with two or three tons of ore and the process could be stopped at any time when a smaller quantity had been worked. It was thus ideal for the small partnerships, enabling them to smelt up small parcels of ore near their mines, saving considerable expense in carriage and in the storage that would be needed for parcels worth sending to the central mill. The smelted lead was divided at the mill into dues ranging from a fifth to a ninth and the "duty" lead was then either delivered to the lord's Agent or left to accumulate at the Mill and to be accounted for at the year end.

As the reverberatory furnace came more into use it was natural that trials should be made of ore hearth against furnace, on similar parcels of ore, and one such trial is given here as a sample. A factor that must be kept in mind is the possibility of having the ore hearth near the mine and so reducing the cost of transport of ore before smelting; the reverberatory furnace was often dominated by the cost of transport of coal to feed it, and was often a long way from the mines. The following trials were made for the agents of the Duke of Devonshire.

1814 Sept. 5th. Then weighed 20 tun of Buckden Gavle Ore at Buckden by 112 lbs. to the cwt. Ten Tun of it was Smelted at the Birks Mill at Buckden and the other Ten Tun at the Cupola at Grassington in order to try the Experiment whether the Birks Mill or the Cupola made the better Produce in Lead and also the Expence of Smelting and Carriage of the Ore from the Mine to each place and the Lead to Skipton from each place.

From Ten Tun of Ore by 112 lbs to the Cwt made in Lead 6 Tun 11 pigs.

This ore did not weigh out it was 2 cwts & 1 qr short weight.

Expence of Carrg. of Ten Tun of Ore from the Buckden Gavle Mine to the Birks Mill 13s. per Tun in Lead	4	5	1
Expence of Smelting and Knocking Slaggs per ton in Lead 12s.	3	18	7
Expence of fuel per ton in Lead 11s.	3	12	0½
Carr. 6 ton 11 pigs of Lead from Birks Mill to Sk: 18s. p.tn.	5	17	11
Expence of Liquor to the Smelters 1 s.p.day for ten days		10	0
One man dressing the Slaggs 2 days @ 3 s.p.		6	0
	18	9	7½

This is the whole cost of smelting the Ten Ton of Ore at Birks Mill. The produce of Lead was 6 tuns 11 pigs.
Jos. Mason attended the whole of the Smelt.
31st Sept. 1814. The Produce as follows from Ten Tun of Ore by 112 lbs. to the Cwt. made 6 Ton 13 piggs of Lead.

N.B. this ore weighed out short weight 3 cwts. 2 qurs. the above 6 Ton 13 pigs was 252 lbs over.

Expence of the carriage of the Ore from Buckden Gavle to the Cupola is £1. 9. 0. in Lead	9	12	11
Expence of smelting 11 shifts @ 13s. per	7	3	0
Carr: of 6 Ton 13 pigs of Lead from the Cupola to Skipton @ 10s.p.ton	3	6	6
	20	2	5

This is the whole expence in smelting Ten Tun of Ore at Cupola.
Produce in Lead 6 Ton 13 pgs which is 2 pigs in favour of the Cupola.
Thomas Wiseman attended the whole of this Smelt at the Cupola.

This is the whole of the account and it passed without any further comment. The produce of lead was higher but so was the expense greater in more than strict proportion. The ore hearth in this test remained slightly the cheaper, even though it appears from the account that its slags had to be dressed and resmelted in the hearth but this was not necessary from the reverberatory. Through the whole history of the Wharfedale mines, the ore hearth remained in constant use at all the outlying mills, with reverberatories only at the central mill, the Cupola on Grassington Moor, which was partly engaged in smelting duty ores and partly in refining. In Wensleydale and Swaledale, the ore hearth held its own with little serious competition from the reverberatory. At Keld Heads Smelt Mill, the principal mill of Lord Bolton's royalties, the ore hearth was kept in use and was subjected to close experiment and improvement of design. The furnaces and their operation there are fully described by Percy and their efficiency is nowhere challenged.

In Alston Moor the two types of smelting proceeded side by side, the London Lead Company favouring the reverberatory furnace for smelting and refining, and keeping the slag hearth for black slag smelting. The Greenwich Hospital and the Beaumont concerns kept a large proportion of ore hearths at work and used reverberatories in a subsidiary role for refining. The smaller independent mills were entirely in favour of the ore hearth.

It seems a fair conclusion that on the score of overall efficiency, when the ease of obtaining fuel, and the fuel requirements of the two types are kept in mind, there is little to choose between them. The adaptability of the ore hearth to mixed and low grade fuels and to working small packets of ore, counterbalance the greater efficiency of the reverberatory furnace, with its stricter demands on the fuel quality, and the much larger capacity for continuous processing.

Metamorphism of Rocks by the Whin Sill

J. A. Smythe, Ph.D., D.Sc.

The following observations arose out of the analysis, for industrial purposes, of samples of limestone from the quarry at Barrasford, north Tynedale. The section in the quarry is about 400 yards long and the beds dip at a low angle to the south east. The whin is exposed as a sill, 60 feet thick in the main, rising at the north end, in the form of two hummocks, to a maximum thickness of 90 feet. The whin is underlain by limestone, which forms the floor of the quarry. Overlying it is a bed of good limestone A, 12 feet thick. Upon this is a poor limestone B, 2 feet thick, with a cover of 1 foot of soil. These two limestones are cut off at the north end by the whin hummock, and they are penetrated in one place by a whin offshoot in the form of a small dyke, 2 feet wide. At the north end of the quarry there is a small inclusion of sedimentaries at the base of the whin. This includes a limestone C, 3 feet thick, which rests on an altered shale D, 2 feet thick. The general arrangement of these rocks is shown in Fig. 1.

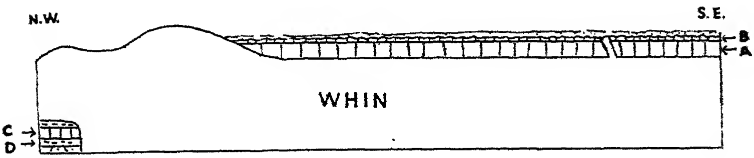

Fig. 1.

Section in Barrasford Quarry.
(Description in text)

Two of the most important industrial uses of limestone are as a fertiliser and as a flux in the smelting of iron ore. In each case the active constituents are the carbonates of lime and magnesia, especially the former. Metamorphism of an impure limestone may bring about a species of self-fluxing, whereby the silica and alumina of the impurities react with the carbonate of lime, carbon dioxide being eliminated and new minerals formed. The extent to which a limestone loses its beneficial properties by such changes cannot be gauged accurately from a mere inspection of the analytical figures. The soluble lime, for example, is derived not only from the carbonate, but also by reaction of the acid used in dissolving the rock upon the partly-soluble metamorphic minerals; and if the limestone contains phosphate and sulphate of calcium, these also are taken into solution.

The amount of matter insoluble in acid may be a better index, but it may contain original insoluble minerals, like quartz, and even if it consists entirely of metamorphic minerals, these may have varying resistance to attack by the acid. Carbon dioxide is a surer guide, though lacking in quantitative significance. The following method, though approximate, is perhaps the best one for obtaining an estimate of the value of the limestone for the purposes specified above.

As magnesia in these carboniferous limestones is usually low, the amount dissolved by the acid may be taken to be present as carbonate. The carbon dioxide equivalent to this is calculated, this deducted from the total carbon dioxide, and the lime equivalent to the difference between the two values for carbon dioxide is calculated.

Below are given the analytical figures for the three limestones; also the values for the carbonates calculated by the method just described, and the amount of lime in solution which is not derived from the carbonate.

ANALYSES OF THE LIMESTONES

	A	B	C
Insol in dil. HCl.	2.20	11.45	2.85
Soluble in dil. HCl.			
Al_2O_3	1.69	0.84	1.97
Fe_2O_3		2.45	2.35
MgO	0.85	1.01	3.18
CaO	53.25	49.80	49.55
CO_2	41.50	33.90	38.20
S	nil	0.10	n.d.
P_2O_5	0.06	0.21	n.d.
H_2O	0.72	0.45	0.19
Organic matter	nil	tr.	1.04
	100.27	100.21	99.33
$MgCO_3$	1.6	1.9	6.1
$CaCO_3$	92.6	75.0	80.3
Total Carbonate	94.2	76.9	86.4
CaO not derived from carbonate	1.3	7.8	4.6

In the light of these figures A is an excellent limestone, B a very poor one and C is intermediate in value. For the industrial uses mentioned above, 5 tons of B would only have the same fertilising and fluxing value as 4 tons of A, and for furnace-work B would have the additional disadvantage that the yield of slag would be greatly increased.

Under the microscope A appears as a coarse-grained, saccharoidal limestone, B and C are of irregular grain, but not definitely saccharoidal; in none of them are the metamorphic minerals well shown, though this might be expected in the case of B at least*. They were isolated from B by dissolving the rock in cold, dilute hydrochloric acid. The insoluble residue was washed thoroughly, dried, and gently crushed between thumb and forefinger. All passed through the 30-mesh sieve, yielding the fractions 30-60 mesh, 14 p.c.; 60-100 mesh 43 p.c.; and under 100 mesh 43 p.c.

The anaylsis of the finest fraction is given in the table below (I) and it points to a content of free silica and a highly hydrated alumino-silicate of the chlorite type.

The coarsest fraction had a greenish tint. After repeated treatment in bromoform it yielded sinks of the composition (2). Alternate action of alkali and acid on this removed material of chloritic composition and final floatation in bromoform gave the product (3). The microscopic examination of this by Dr. L. Hawkes showed it to consist essentially of grossularite and vesuvianite, in roughly equal amounts, the characters of the minerals being:

grossularite—R.I. 1.74 ± .005. Mainly isotropic; some large grains show anomalous birefringence

vesuvianite—R.I. 1.715 ± .003. Birefringent, weakly optically negative; some good crystalline outlines and prismatic cleavage.

The floats from this preparation contained chloritic minerals.

* The contact minerals of the whin sill have been investigated with petrographic detail by W. M. Hutchings **Geol. Mag.** 1898, pp. 69-82; 123-131. He found impure limestones to contain garnet, augite, idocrase, wollastonite, epidote, hornblende, anorthite, chlorite and sphene. See also L. Wager **Geol. Mag.** 1928, pp. 88-91; 1929, 77-110; 221-238.

PREPARATIONS FROM LIMESTONE B

	1	2	3
SiO_2	55.4	34.60	38.60
TiO_2	—	0.36	0.86
Al_2O_3	12.8	23.99	22.87
Fe_2O_3	—	4.46	0.36
FeO	—	1.56	1.99
MgO	3.0	2.14	2.10
CaO	17.0	27.80	32.50
H_2O	11.5	4.85	0.71
	99.7	99.76	99.99
S.G.	—	—	3.34

1. Finest material, under 100-mesh, white.
2. Heavy crop from fraction 30-60 mesh.
3. Sample 2 after treatment with alkali and acid and separation with bromoform.

The composition 3 corresponds roughly with that of a mixture of equal weights of grossularite and vesuvianite.

THE MATERIAL E

This, (see Fig. 1) is essentially the residue from the weathering of the limestone B and it occurs in large quantity in the hollows of the limestone under a thin cover of soil. A sample lightly stained with limonite was selected. It is easily crumbled when dry and the powder, on sieving, yields similar fractions to the residue left on solution of the underlying limestone with acid.

The fraction 100-120 mesh was examined in detail. The analysis of this in the crude state is given in the table below (I) and from this the proximate composition is calculated as:

$CaCO_3$	10.9
$2Fe_2O_3.3H_2O$	5.8
H_2O	1.2
Metamorphic minerals	82.1
	100.0

From analysis (1) the composition of the crude metamorphic minerals (insoluble in dilute acid) can be calculated (2). This insoluble matter on separation in bromoform yielded 95 p.c. of sinks of the composition (3). Assuming that the lime in (3) is entirely present as grossularite (the ideal composition of which is given in (4) then the remainder (5) would represent roughly the chloritic, and possibly also kaolinitic, contaminants of the garnet.

	1	2	3	4	5
SiO_2	29.40	35.8	38.60	40.0	28.8
TiO_2	—	—	0.86	—	—
Al_2O_3	21.87	26.6	22.87	22.7	33.1
Fe_2O_3	4.99	—	0.36	—	—
FeO	2.70	3.3	1.99	—	8.8
MgO	4.82	5.9	2.10	—	15.7
CaO	25.30	23.3	32.50	37.3	—
CO_2	4.80	—	—	—	—
H_2O (—)	1.20	—	—	—	—
H_2O (+)	5.07	5.1	0.71	—	13.6
	100.15	100.0	99.99	100.0	100.0
S.G.	—	—	3.27	—	—

1. Crude material E.
2. Calculated composition of residue after treatment of E with dilute acid; i.e., after removal of calcite and limonite.
3. Sinks in bromoform from insoluble residue of E.
4. Composition (ideal) of grossularite, $3SiO_2$, Al_2O_3. 3CaO.
5. Calculated composition of chloritic and kaolinitic contaminants of garnet (3).

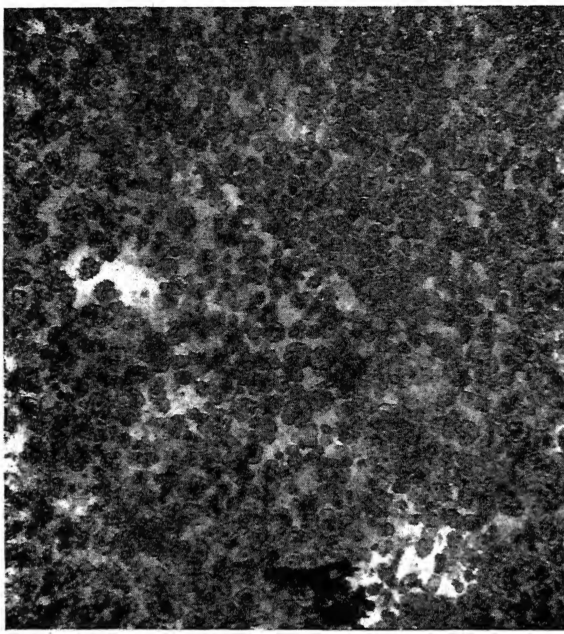

FIG. 2.

Ordinary Light × 22.

Rock E, from solution hollows in limestone B. Grossularite grains in cement of calcite and chlorite.

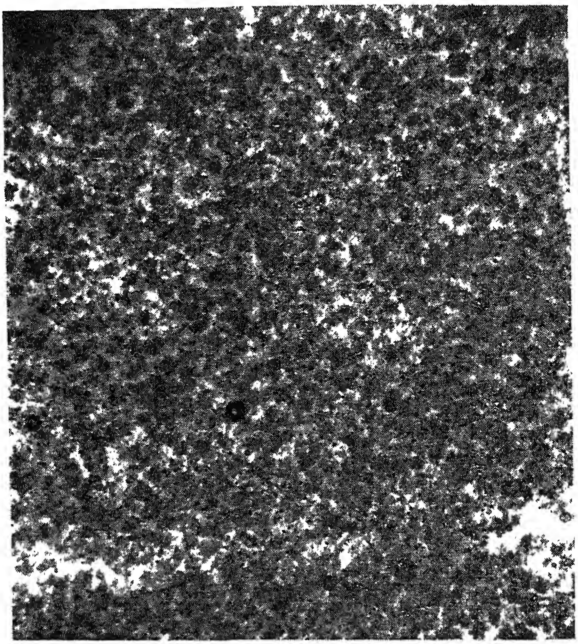

Fig. 3.

Ordinary Light × 22.

Rock D. Spotted argillite (cum). Lower contact of whin. Barrasford

The results of the chemical examination are in good agreement with those of the microscopic investigation, reported by Dr. Hawkes.

"The crude material E shows in section an aggregate of close-set garnet grains in a matrix of large calcite grains, green chloritic matter, and some black opaque material. Calcite is the predominant cement, each crystal enclosing a host of garnets. Considerable areas have chloritic cement; vesuvianites are rare." The purified material, of which the analysis is given in (3) was found, on microscopic examination, to consist "largely of grossularite, though a little chlorite clings to the grains of the garnet."

Fig 2 shows a photomicrograph of the crude rock E.

The chief metamorphic minerals in the impure limestone B are grossularite and vesuvianite and they are present in approximately equal amounts. With them are associated chlorite and clay minerals and possibly some quartz. The weathering residue E is composed mainly of grossularite, vesuvianite being quite subsidiary, and these minerals are contained in a cementing material, mostly calcite, with a moderate amount of chlorite, the whole being impregnated with limonite, which varies greatly in quantity from place to place.

It may be granted that the garnet was all originally present in the limestone. Most of the vesuvianite which accompanied it has, however, succumbed to the action of the weathering agents, and it is probable that the greater part of the chlorite is derived in that way. There is a possibility that some may have come from the destruction of garnet, and some may have been transferred, maybe with change in composition, from that pre-existing in the limestone. Some of the cementing process is the work of this chlorite, but the major part comes from calcium carbonate, which requires no elucidation.

THE ALTERED SHALE D

This has a faintly green colour, becoming light grey on grinding and light brown on ignition. It has the plastic properties of a good clay and is of the kind from which slate pencils were often made in the past. Such shale is generally known as 'cam' in Northumberland; locally it is called 'cum.' It has been used sometimes in the neighbourhood for making chimney pots, and found very suitable for that purpose. The shale takes a good polish; it is a spotted argillite, free from detrital quartz, having about 60 spots per square millimeter. Its composition is as follows:

SiO_2	53.25
TiO_2	1.00
Al_2O_3	26.61
FeO	3.69
MgO	1.87
CaO	0.90
Na_2O	0.36
K_2O	3.60
P_2O_5	0.09
S	0.04
$H_2O(-)$	2.89
$H_2O(+)$	5.39
	99.69

The composition is similar to that of many of the local fire-clays*, though the potash is somewhat higher than usual. A photomicrograph of the cum is shown in Fig 3.

Fragments of this rock were heated for three hours at various temperatures up to 850°C. The loss of water is 40 p.c. of the total present at 110°, 53 p.c. at 500° and 90 p.c. at 600° After cooling, the samples were immersed in water for some time and then allowed to dry in air. Those which had been heated below 400° were found to have absorbed almost all the water lost on heating and to give this is up again at 110°. In other words, they had reverted to their original state of hydration. The samples which had been heated at 500-600° and upwards, however, absorbed only that amount of water which corresponded to their hydroscopic moisture, losing this at 110°, so that the chemically-combined water had all been expelled, and there was consequently no possibility of the shale returning to its natural condition.

It may be concluded, therefore, that this cum has not been exposed in nature to a higher temperature than 500°-600°C, and that the metamorphism it has undergone, manifested by the development of spots, has taken place at this relatively low temperature.

Such were the conditions, then, at the bottom of the sill. There is no means of estimating the temperature attained at the top of the sill, but it was probably a good deal higher; for not only has the 12-foot good limestone been recrystallised, but there has been extensive metamorphism of the overlying bad limestone, in which the presence of aluminous and siliceous impurities afforded the necessary chemical conditions. Whether or not the metamorphic processes have been stimulated by the transference of emanations from the magma below cannot be decided, but it seems probable that this is a case of pure thermal metamorphism.

My thanks are due to Dr. L. Hawkes for his petrographical examination of the materials, the reports on which are quoted above, and also for the excellent photomicrographs reproduced in Figs. 2 and 3.

* v A. A. Hall. These proceedings, 1911. Vol. 4, Pt. 2, p. 83.

Measurements of the Absorption of Sound in Water at 358,540,1074 and 1790 kc/s.

by

A. Van Itterbeek† and A. De Bock*

(Physical Laboratory-Louvain)

Measurements of the absorption coefficient (α) of sound in liquids have been made the last few years by using four kinds of experimental methods:—

(1) the optical method, as used by Bär[1] and Biquard.[2]

(2) the pulse technique which has been developed during the war by American investigators (Pellam and Galt,[3] Kittel[4] and Teeter[5]).

(3) the radiation pressure method, whereby the radiation pressure is measured by means of a reflector fixed to one arm of a balance (Sörensen,[6] Claeys, Errera and Sack,[7] Hartmann and Focke[8]) or by using a crystal microphone (Labaw and Williams[9]).

(4) the method of the hot wire microphone as developed by Richardson.[10]

The measurements using the optical and pulse method were made at frequencies higher than one megacycle, and from the experiments it could be concluded that α/γ^2 is independent of frequency (γ) with a constant value of 70.10^{-17}.

On the other hand discussion has arisen about the results obtained by Sörensen, Hartmann and Focke. Those investigators, using the radiation pressure method, with frequencies lower than one megacycle, found a pronounced increase for α/γ^2 as a function of frequency (see fig. 1).

Claeys, Errera and Sack checked the results obtained by Sörensen and found absorption coefficients which were about a hundredth of those of Sörensen.

* Visiting Professor, under a British Council Foundation, to King's College, Newcastle-on Tyne, March, 1948.

† Research fellow of the I.R.S.I.A.

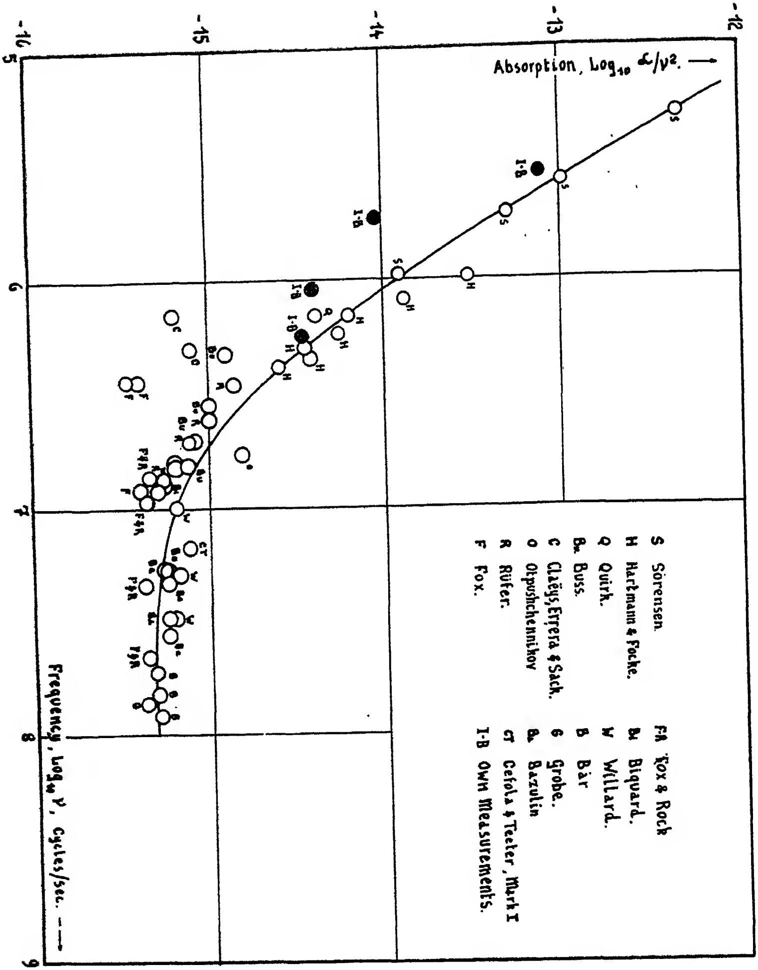
-16
-15
-14
-13
-12
5
6
7
8
9
Absorption, Log10 α/ν² →
Frequency, Log10 ν, Cycles/sec. →
S Sörensen.
H Hartmann & Focke.
Q Quirk.
Bu Buss.
C Claëys, Errera & Sack.
O Otpushchennikov
R Rüfer.
F Fox.
F&R Fox & Rock
Bi Biquard.
W Willard.
B Bär
G Grobe.
Ba Bazulin
CT Cefola & Teeter, Mark I
I-B Own Measurements.

fig. 1.

[1] R. Bär, Helv. Phys. Acta; *X*, 333, 1937.
[2] P. Biquard, C. R., Paris, *197*, 309, 1933.
[3] J. Pellam and J. Galt, Jour. Chem. Phys., *14*, 608, 1946.
[4] C. Kittel, Journ. Chem. Phys., *14*, N°10, 614, 1946.
[5] C. Teeter, Journ. Acoust. Soc. Amer., *18*, N°2, 488, 1946.
[6] C. Sörensen, Ann. d. Phys., *24*, 121, 1936.
[7] J. Claeys, J. Errera and H. Sack, Trans. Far. Soc., *189*, 136, 1936.
[8] Hartmann and Focke, Phys. Rev., *57*, 221, 1940.
[9] L. L. Labaw and A. O. Williams, Journ. Acoust. Soc. Amer. *19*, 30, 1947.
[10] E. G. Richardson, Proc. Phys Soc., *52*, 480, 1940.

One of their arguments was that the diameter of the reflector used by Sörensen was too large compared with the diameter of the tube in which the measurements were carried out. Sörensen used a tube with a diameter of 8 mm. and a plane reflector of about 4 cm. diameter.

We have the opinion that the use of a plane reflector has brought to Sörensen great difficulty due to the fact that such a reflector is very unstable when standing waves are built up between the crystal and the reflector.

Claeys, Errera and Sack used as a reflector a hollow sphere of 2 cm. diameter in a tube of 12 cm. diameter.

Hartmann and Focke used a brass cone reflector having a basal diameter of 2.5 cm. which was suspended in a brass tube having a diameter of 11 cm.

The purpose of our measurements was to check those results obtained by Sörensen, Hartmann and Focke on one hand and those obtained by Claeys, Errera and Sack on the other hand.

During preliminary measurements we could observe that special precautions had to be taken in order that the radiating surface of the quartz crystal is exactly perpendicular to the tube axis. When the direction of the crystal surface was changed by means of the three regulating screws (fig. 2), we found that in some cases the radiation pressure registered by means of the balance changed with a factor of ten. The explanation of this phenomenon can be given as follows: Firstly we must remark that in general the distribution of the radiation of a quartz crystal is a small leaf-form beam as has been observed by Hiedemann*. When the ultrasonic radiations enter in oblique

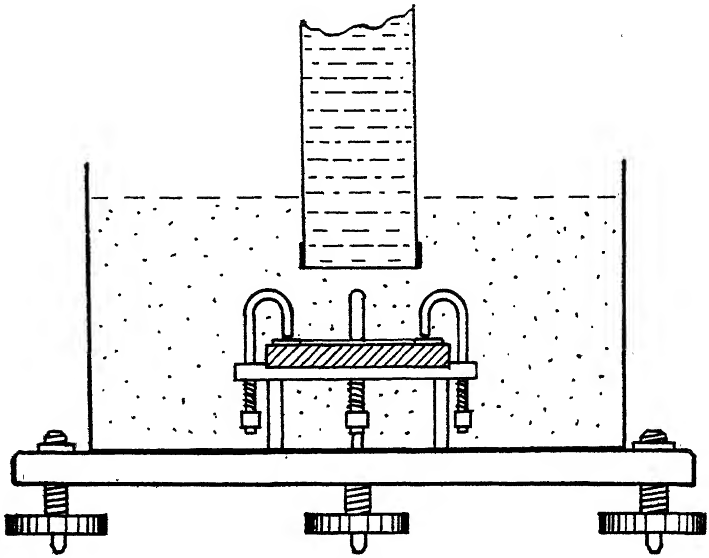

Fig. 2.

directions into the tube, reflections also will occur on the tube walls and in such a manner that at some distances it may happen that the ultrasonic radiations miss the reflector. Practically it is impossible to realize a complete perpendicularity of the quartz surface to the axis of the tube. So we think that in order to measure exactly the total radiation pressure it is more certain to use a reflector which closes the tube nearly completely as a piston.

* E. Hiedemann, Ultraschall Forschung, 1934, f106-109, Walter De Gruyter & Co., Berlin.

Before starting an absorption measurement the position of the crystal was regulated by means of the screws to give a maximum radiation pressure reading at the upper end of the tube (length of the tube: 1.5 m.) Afterwards we also checked the radiation pressure at different heights of the reflecting sphere and we found that the radiation energy was also a maximum in those positions.

The experimental apparatus and the mounting of the quartz crystal are respectively represented in fig 2, 3, 4.

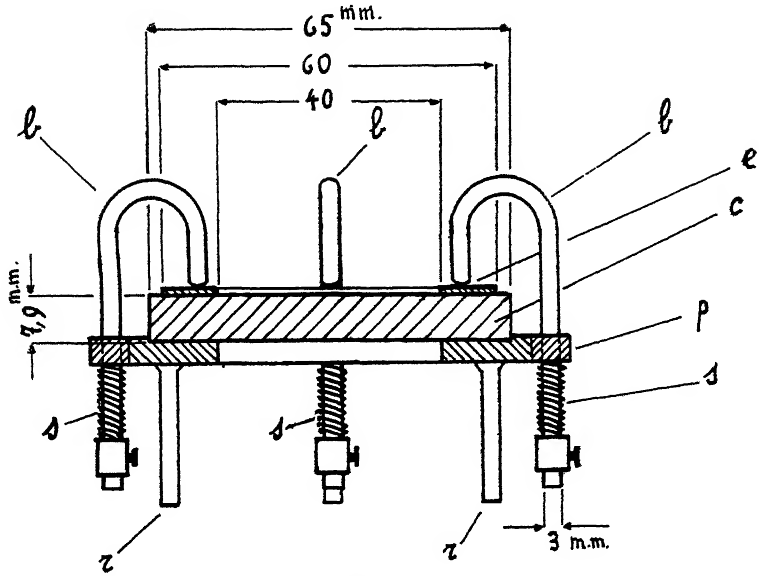

Fig. 3.

The mounting of the quartz crystal used is the same as that used by Freundlich, Rogowski and Söllner[11] (see fig. 3). The crystal C used had a resonance frequency of 358 kc/s. (diameter: 66 mm.; thickness: about 8mm.) but measurements were also carried out using the third and fifth harmonics. One measurement was carried out with another crystal having a resonance frequency of 540 kc/s.

A ringform electrode (*e*) (thickness 1 mm.) accurately turned on the lathe is pressed by means of curved glass rods (*b*) and steel springs (*s*) on the upper crystal face. The crystal is placed on a brass plate (*p*) with three supporting glass rods (*r*). This mounting is placed in a vessel (see fig. 2) containing pure paraffin-oil to insure sufficient electrical insulation, the whole being supported by a bakelite plate on three regulating screws. These screws are used to adjust accurately the quartz crystal surface.

For the measurements at frequencies 358 and 1074 (third harmonic) kc/s. the crystal was driven by means of a 100 Watt oscillator with variable frequency change from 200 to 1200 kc/s. For the measurements at frequency 1790 kc/s. (fifth harmonic). we used a 1.5 kWatt transmitter with a variable frequency from 1790 to 3500 kc/s.

11 Freundlich, Rogowski and Söllner, Kolloid Beihefte, *37*, 223, 1933.

It was impossible to measure the absorption-coefficient at still higher frequencies because from the seventh harmonic the vibration-energy of the quartz crystal became too small to detect it with the same balance method.

The voltage applied to both faces of the quartz crystal, measured with a Starke and Schröder electrostatic voltmeter (*V*-see fig. 4) never exceeded 2 kVolts except for the measurements with the fifth harmonic (5 kVolts). The measuring tube *T* is a glass tube (length 1,5 m.; diameter 4,0 cm.). As a reflector we used a brass hollow sphere (*R*) diameter 3,2 cm. suspended by means of a cotton thread to one of the arms of a milligram balance (*B*). The deflections of the balance are measured on a scale (*S*) by means of a reflecting mirror (*M*). The balance itself is placed on a vibration-free column (*P*). The tube *T* is closed at the lower end by means of a thin copper plate which is soldered on a copper ring sealed to the tube. The thickness of the copper plate for the measurements on frequency 358 and 1074 kc/s. was 0,1 mm. For the measurements in the fifth harmonic we used a brass plate of which the thickness (4,09 mm.) has been computed, considering the results obtained by Boyle and Rawlinson[12] to produce maximum transmission.

The radiation pressure was determined at different heights by changing the length of the suspending wire. At each measuring run the logarithm of the balance deflection was plotted against the distance crystal-reflector, and the absorption-coefficient computed from the angular coefficient of the straight line obtained. We could observe that during the measurement the reflector was completely quiet and not subjected to oscillations. The experimental results on pure distilled water are given in table I.

The results of table I are indicated on fig. 1. We see that our experimental results are a little lower than those of Sörensen and also those of Hartmann and Focke.

[12] R. W. Boyle and F. W. Rawlinson, Trans. Roy. Soc. Canada, (3), 22, 55, 1928.

TABLE I

Absorption of ultrasonics in water

Date	γ kc./s	α cm.$^{-1}$	$\alpha\gamma^{-2} \times 10^{17}$	Average Value
17/12/47	1 × 358	0,0089	7000	
17/12/47	,,	0,0095	7400	
17/12/47	,,	0,0131	10200	
17/12/47	,,	0,0118	9200	8100
29/1/48	,,	0,0092	7200	
5/2/48	,,	0,0101	7900	
29/1/48	1 × 540	0,0022	780	780
18/12/47	3 × 358	0,0059	550	
7/1/48	3 × 358	0,0035	325	437
25/2/48	5 × 358	0,0107	335	
25/2/48	5 × 358	0,0107	335	335

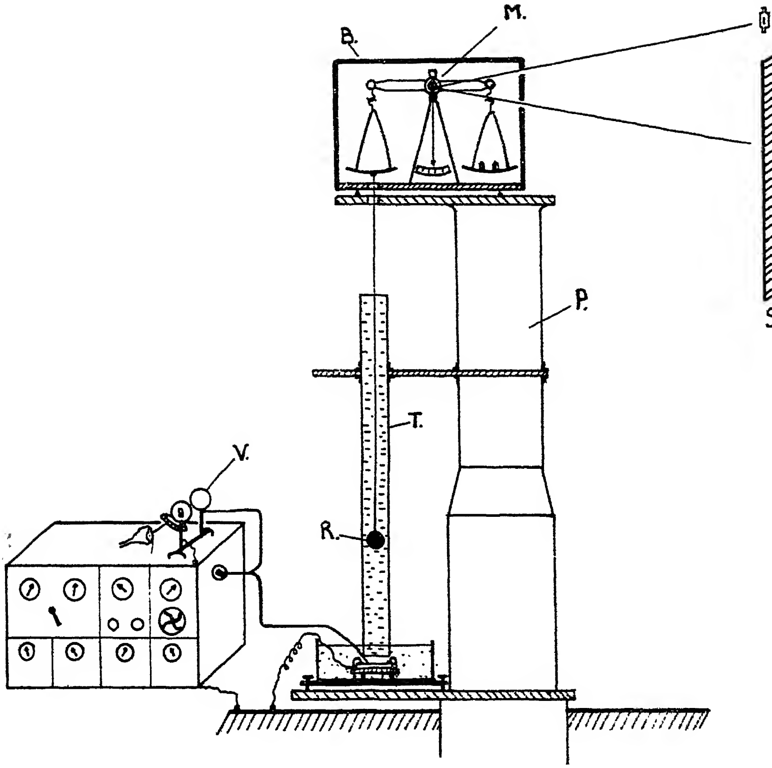

fig. 4.

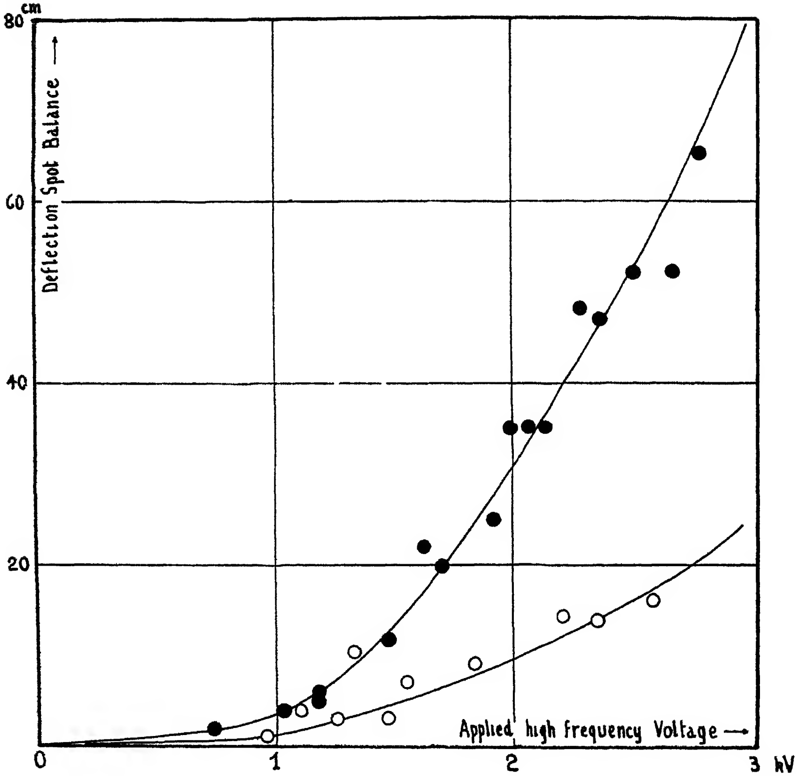
80 cm
60
40
20
0
1
2
3 kV
Deflection Spot Balance →
Applied high frequency Voltage →

Fig. 5.

The experimental results of table I were obtained after a great number of preliminary investigations, thereby using different lengths of tubes, different diameters, different types of reflectors and different acoustical energy. Our opinion is that to obtain concordant data, precaution must be taken that the used acoustical energy is not too large. The values obtained for the absorption must be found to be independent of the acoustical energy. In fig. 5 are indicated the acoustical energy at two positions of the reflector and corresponding with different values for the voltage applied to the quartz crystal. We see that the ratio between the acoustical energies is independent of the applied high frequency voltage (see table II).

TABLE II

Applied Voltage K volt.	Deflection Balance at 17 cm.	Deflection Balance at 131 cm.	Deflection Ratio
1.35	3.2	8.0	0.40
1.50	4.8	13.6	0.35
1.75	7.0	22.0	0.32
2.00	9.6	30.8	0.31
2.25	12.8	41.6	0.31
2.50	16.2	52.8	0.31
2.75	20.4	68.0	0.30

As a general conclusion it seems to us that α/γ^2 increases as a function of frequency as has been found by Sörensen and by Hartmann and Focke.

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